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STRENGTH OF GLASS— A REVIEW OF FOUR RECENT PAPERS

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In the December 1944 issue of the *Journal of the Society of Glass Technology* (Vol. XXVIII, No. 130), there appeared four papers concerned with the elastic, viscous, and strength properties of glass.

These papers not only offer important new contributions, but also provide an excellent survey of previous work and ideas on the strength of glass and closely related matters. Because their subject matter is so inter-related,it seemed appropriate to present condensations of all four papers in one review.

Strength of Glass Fibres—Part I— Elastic Properties (Page 368)— By J. B. Murgatroyd

Glass fibres exhibit strengths which are very high when compared with those of massive pieces of glass. For instance, Griffith in 1920 reported a strength of 350 kg/mm^2 for fibres of 4×10^{-5} cm diameter. Such a value is roughly 70 times the strength measured on massive pieces, and consequently is often termed "anomalous." Actually, however, the strength of fibres begins to approach the estimated strength of the primary bond in glass, 1000 kg/mm^2, and hence the strength behavior of fibres might be considered even more "normal" than that of massive pieces.

Griffith was of the opinion that the strength of fibres was consistent with his theory of flaws. Due to the small dimensions or to the act of drawing, surface molecules would be lined up with directions of maximum attraction predominantly parallel to the axis of the fibre. There would be a similar orientation of flaws with an attendant increase in tensile strength. However, it is difficult to understand on this basis why there should be a steady increase in strength with decrease in fibre diameter.

Other possible explanations of fibre strength are (1) that reduction of diameter simply decreases the probability of meeting a Griffith flaw, (2) that the elastic constants of a material are changed when it is reduced to a fibre, or that (3) the constitution of the glass suffers an alteration. With regard to (2), it is pointed out that an increase in Young's modulus should lead to a recorded increase in strength if we subscribe to the constant strain theory of breaking, since a greater stress would then be required to produce the breaking strain. If the increase in strength is due solely to (1), no change in elastic constants with diameter should be found, whereas if (3) is responsible, changes in the elastic constants might be expected, but these would not need to be as drastic as required under (2). The determination of Young's modulus and the modulus of rigidity form the principal portion of Mr. Murgatroyd's paper, followed by a de-

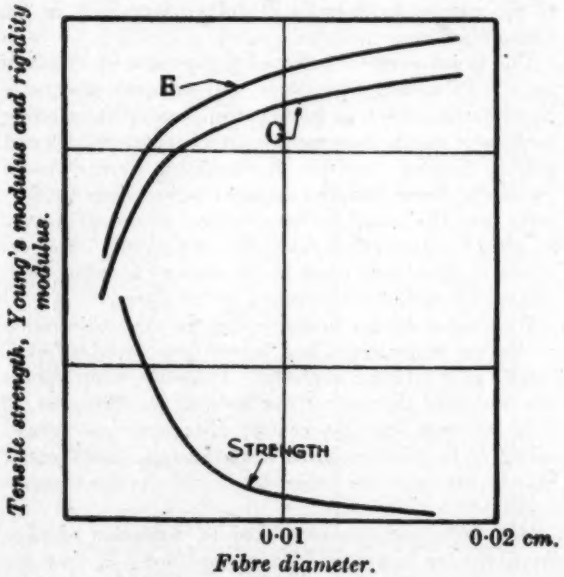

Fig. 1. Effect of Fibre Diameter on the Value of the Tensile Strength, Young's Modulus (E) and Rigidity Modulus (G).

scription of the effects of heat treatment on them. The general result obtained is that both moduli decrease with decreasing fibre diameter while heat treatment increases them. Attention is therefore focused on (3) as a principal contributory to the remarkable strength of fibres.

The modulus of rigidity G of a fibre was measured first, by findng the period of oscillation of a horizontal disc supported by the fibre. Then Young's modulus E was determined by supporting the fibre between knife edges, loading it, and measuring the deflection. On the finest fibres the estimated accuracy was about ±6%. Seventy fibres were used, drawn by hand from a rod of glass of composition: SiO_2 69.1, Fe_2O_3 0.07, Al_2O_3 3.9, CaO 5.6, MgO 1.3, Na_2O 19.4. Lengths were 15-20mm. Table I shows selected mean values of Young's modulus and of the modulus of rigidity, as well as the calculated Poisson ratio:

TABLE I

(Murgatroyd Table I)

Mean Values of Young's Modulus, Rigidity Modulus and Poisson Ratio for Selected Glass Fibre Diameters.

Diam. cm	$Ex10^{-11}$	$Gx10^{-11}$	σ
0.002	4.44	2.14	0.04
0.004	5.74	2.49	0.15
0.008	5.95	2.63	0.13
0.011	6.06	2.68	0.13
0.100	6.94	(2.85)	0.22

Both the elastic constants E and G decrease with decreasing fibre diameter, the drop in each becoming very pronounced below 40 microns fibre diameter, at which point Griffith noted that the strength began to increase rapidly; see Fig. 1. Numerically, Table I shows a percentage decrease in E of 36%, in G of 25%. Griffith records a sixteen fold increase in strength over this range of diameters. This enhanced strength can scarcely be ascribed to the change in Young's modulus, since it is in the wrong direction.

Due to inaccuracies in E and G the value of Poisson's ratio σ calculated from them will be quite uncertain. Nevertheless σ shows a falling trend, indicative of aeolotropism, since the two moduli are changing at different rates. In other words, with decreasing fibre diameter the lateral bonds may be assumed to be affected differently than the bonds in the direction of the fibre axis, in accord with Griffith's original hypothesis. The decrease in the elastic constants themselves is strong indication of constitutional changes in the glass.

It does not appear probable that the mere orientation of surface molecules a few layers deep could affect E and G to the extent observed. Evidently some change has occcurred throughout the body of the fibre, for, if it be assumed that the central fibre core has normal values of the elastic constants, the surface layers would have to have negative values to account for the observations.

Heat treatment was next used to determine whether the fibres are in an equilibrium condition. If they are not, a change in elastic constants would be expected by treating them near the softening point, 520° C for the particular glass used here. In the fibre diameter range

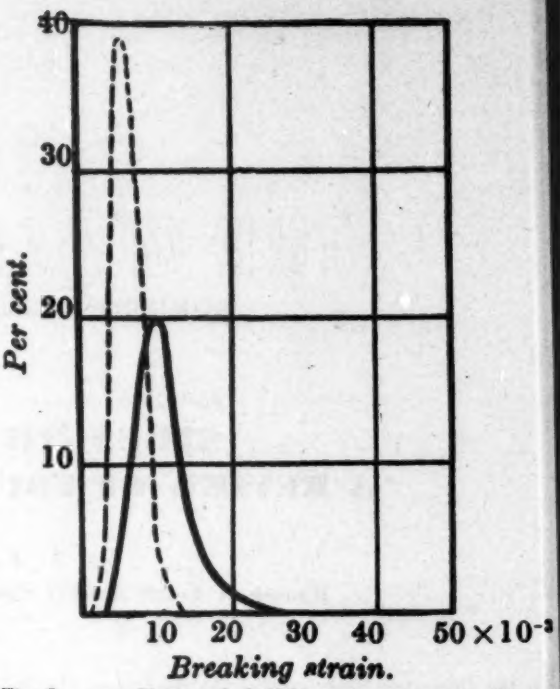

Fig. 2. —— Untreated, 0·012 cm. diameter —— Heated to 520°, 0·016 cm. diameter.

18-122 microns, an increase in both E and G of 6% was observed after heating for 30 minutes at 550° C., whereas no change occurred for the larger diameters, 0.3 and 1.0mm. Moreover, on the smaller diameters, the final value of the rigidity modulus G was reached in a much shorter time than that required by Young's modulus. When the temperature was dropped to 320° C. the 6% increase in G was still obtained at a rate very little slower than at 550° C., whereas Young's modulus remained unchanged at all temperatures below the softening point. In view of these results the condition of the fibres cannot be regarded as one of equilibrium for low temperatures, but rather for some higher temperature range.

Some notion of the viscosities of glass in fibre form was obtained by various bending experiments during or after heat treatment and noting under what conditions the fibres would take a permanent set. Thus for example a fibre can be permanently deformed by holding it bent for an hour at only 100° C. The conclusion was reached that the viscosity of the finest fibres is abnormally low. It can be raised somewhat by heat treatment, the degree increasing with temperature.

These viscosity phenomena introduce an entirely new element into any consideration about the strength of glass fibres, and they must be considered in connection with the changes in E and G in attempting to explain the strength properties of fibres. The facts seem to point to a chain structure with greatly weakened lateral bonding.

The Strength of Glass Fibres—Part II—The Effect of Heat Treatment on Strength (Page 388)—
By J. B. Murgatroyd

In the preceding paper it was found that a decrease in

elastic constants of fibres takes place in the range of diameters where, according to Griffith, their tensile strength increases. Since subsequent heat treatment tends toward reestablishment of more normal values of the elastic constants, the question arises whether it also tends to make the strengths more "normal", i.e., decrease them from the "abnormally" high values characteristic of freshly drawn fibres. This was indeed found to be the case, thus completing the picture of the correlation between changes in elastic constants and the strength.

In order to be able to carry out the breaking tests rapidly, a simple bending apparatus was constructed. The fibre, bent as a hairpin, was placed between the jaws of a miniature vise and the jaws closed until fracture occurred. Since the maximum strain in the fibre is given by the ratio of the radius of the fibre to the radius of curvature, the breaking strain could be determined from the jaw separation at fracture, it having been determined that the radius of curvature was directly proportional to this separation. It is to be noted that the maximum strain is limited to a very small area at the convex vertex of the hairpin. The apparatus may introduce some small uncertainties in the strength measurements, due to the changing rate of increase of strain as the jaws are closed at a uniform rate. Comparative strength tests on fibres of equal diameters should, however, not be influenced by this factor.

The fibres were drawn at high temperature from a bead of glass of composition mentioned in Part I. They were left for a few days before testing. Two large groups of fibres were tested, one untreated, the other heated for 15 minutes at 520° C. Mean tensile strengths (as calculated from the observed strains) and Young's modulus are contained in Table II:

TABLE II

(Murgatroyd Table I)

Breaking Strength and Young's Modulus of Untreated Glass Fibres

No. Tested in Group	*Diam. cm*	*Breaking Strain*			*Young's Modulus* kg/mm^2	*Mean Tensile Strength* kg/mm^2
		Mean	*Max.*	*Min.*		
169	0.0025	0.0310	0.090	0.009	5200	161
177	.0040	.0297	0.084	.008	5800	172
189	.0055	.0249	0.082	.007	5900	147
46	.0080	.0163	0.032	.004	6100	100
80	.0120	.00975	0.032	.004	6300	61

(Murgatroyd Table II)

Breaking Strength of Heat Treated Glass Fibres 15 Minutes at 520°C

130	0.0024	0.0157	0.034	0.004	5500	86
119	0.0040	.0140	.026	.006	6100	85
89	0.0057	.0128	.020	.006	6200	79
34	0.0080	.0109	.028	.005	6400	70
45	0.016	.0064	.014	.002	6600	42

The table provides further confirmation of the increase in strength with decreasing diameter. Comparison of the strengths of treated and untreated fibres demonstrates the effect of heat in greatly reducing the strength—halving it for diameters under 50 microns. Auxiliary experiments at a lower temperature, 400° C., produced somewhat less effect on the strength.

Thus the correlation between fibre strength and elastic constants, which exists in freshly drawn fibres, persists after heat treatment; the increase in strength with reduction in diameter is accompanied by a reduction in the elastic constants, while the weakening effect of heat treatment goes hand in hand with an increase in elastic constants.

Of interest are comparative distribution curves, before and after heat treatment, obtained by plotting the percentage of fibres breaking at any given strain against that strain. Figures 2 and 3 are distribution curves for the two extremes of fibre diameter.

The character of these curves speaks strongly for a random distribution of flaws of all sizes. The actual area of a fibre subjected to the recorded breaking strain in the test employed is very small, hence we should expect to find a wide spread in the distribution curves between the minimum and maximum breaking strains. This follows from the fact that in a small area the probability of meeting the severest flaws becomes remote. Furthermore, the spread should increase with decreasing test area, in other words, with decreasing fibre diameter. Comparison of the above curves for two diameters shows this to be the case.

Heat treatment narrows the spread, presumably by increasing the severity of already existing flaws or by developing new ones.

The general conclusion reached in these first two papers, based on observations of the strength, elastic behavior and viscosity of the fibres, is that there is a fundamental constitutional difference between them and the massive parent glass. The change is from the accepted rigid three-dimensional structure toward a chain structure with weak lateral bonding, a condition which does not represent the most stable molecular configuration for a soda-lime-silica glass.

In future experimental work on fibres more attention should be given to the question of the state of "temper" of the fibres, in the reviewer's opinion. From the manner of drawing fibres it may reasonably be expected that they will exhibit compression stresses near the surface, analogous to air-tempered glass. Such a condition should be amenable to examination with the petrographic microscope. This state of strain may be produced not only by the rapid cooling, but also by surface

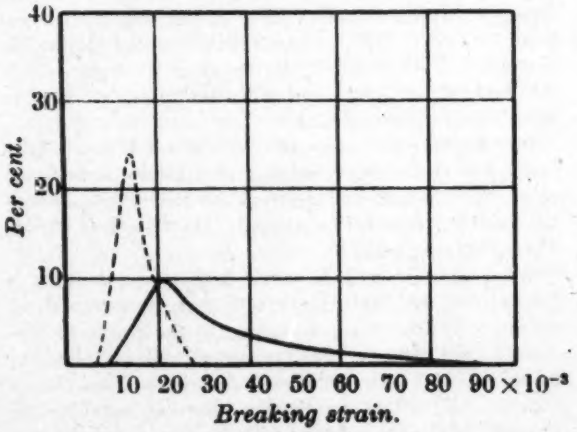

Fig. 3. —— Untreated, 0·0025 cm. diameter —— Heated to 520°, 0·0024 cm. diameter.

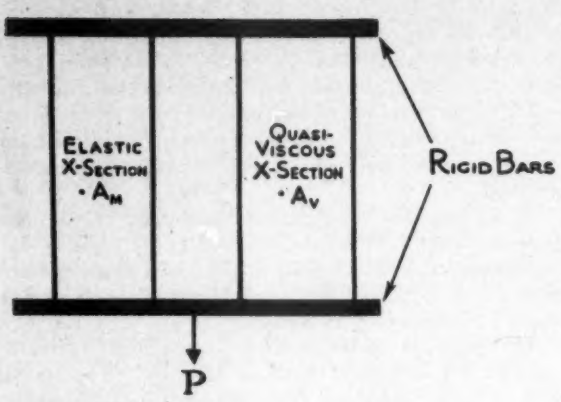

Fig. 4A.

depletion of alkali, as was pointed out by Mr. J. E. Stanworth in the discussion.

The Mechanism of Brittle Rupture in Glass (Page 406)—
By J. B. Murgatroyd

The strength of the primary atomic bonds in glass is probably very high, as judged by the high evaporation temperature and by the high value of Young's modulus. A. A. Griffith estimated it to be of the order of 1000 kg/mm². Actually, the measured values are only of the order of 5 kg/mm², and as Mr. Murgatroyd expresses it, we shall probably have to accept this technical deficiency of glass as one of its standard properties. The discrepancy prompted Griffith to postulate the presence of cracks in great profusion throughout the glass. These would act as stress concentrators and lower the strength as measured microscopically. Calculations indicated that cracks of a few microns length might be responsible. Griffith supported this picture by measurements on deliberately produced cracks.

Griffith assumed his flaws to be actual cracks, but there appears to be no satisfactory direct evidence of their presence. An alternative suggestion is that the "flaws" are weak secondary bonds. Theories on the nature of the flaws must be tested in the light of the following established facts in addition to that of the low technical strength: 1. The more rapidly the load is applied, the greater is the measured strength. 2. The strength may be increased three or four-fold by surface treatment with HF, or somewhat less by drying in vacuum. 3. The interior of the glass is stronger than the surface. 4. Glass can withstand greater strain in shear than in pure tension.

Mr. Murgatroyd points out that the crack theory with associated effects is compatible with all these facts except (1), while the secondary bond theory has difficulties with all four. Consequently, the "Viscous Pocket Theory" is suggested.

When glass is cooled from a high temperature, it is generally agreed that a growth of three-dimensional aggregates results. Now, according to the proposed Viscous Pocket Theory, the interstices will be filled by material which can yield to forces in a quasi-viscous manner. With this assumption, "we can combine the elements of Griffith's theory with the theories of the constitution of glass, and at the same time explain the lack of cracks and the time effect. The rate at which yie occurs will depend on the value of the applied stress a the temperature, and after yield is complete the pock becomes equivalent to a Griffith crack, because the m terial of the pocket no longer carries any stress."

The model proposed to test the viscous pocket theor consists of two parallel cylinders, Fig. 4, one having th elastic properties of the perfectly elastic matrix, th other of the quasi-viscous pocket material. The cyli ders are coupled at their ends by rigid bars, so that th strain is the same in each at all times. For a given loa on the configuration, the distribution of the stresses be tween the matrix and the viscous component is controlle by the relative cross sectional areas of the two cylinder A_M/A_V. To represent the glass as a whole, the ratio i made very large, since the proportion of viscous materia will be small. To represent the detailed condition o stress concentration at the ends of a "crack" (in th language of Griffith), the ratio is taken much smaller "The essential point in this method of representing th phenomena is that the rate of appearance of delaye strain and the rate of growth of stress concentrations i the glass must be connected, since both are controlled b the rate of relaxation of stress in a quasi-viscous com ponent of the glass."

The model may not be treated mathematically to de rive expressions for both the delayed elastic effects and the variation of breaking strength with time. As a basis for the behavior of the quasi-viscous material, the Nutting equation is used in the form

$$St^K = \psi\sigma \qquad (1)$$

Where S is the stress, t the time, σ the strain and K and ψ are constants. K is small corresponding to a high viscosity of the quasi-viscous material, and under this condition the equation may be used to a first approximation, despite the fact that S, t, and σ all vary. Analytical proof of this is given by Professor P. J. Daniell in the appendix.

In a glass behaving like the model the delayed elastic effect is given by

$$\Sigma - \sigma = \frac{C\sigma}{t^K} \qquad (2)$$

where Σ is the strain after a sufficient time has elapsed to allow complete relaxation of the stress in the quasi-viscous material

$$C = \frac{\psi}{E_M}\,\frac{A_V}{A_M} \text{ is a constant} \qquad (3)$$

The variation of breaking strength with time is found to be of the form.

$$P - a = b/t^K \qquad (4)$$

where P is the breaking load which is assumed to occur at a definite strain B in the matrix.

$a = EA_M B$, the limiting load which can be borne for an indefinite time

$b = \psi A_V B$, a constant

The values of A_V and A_M in these two cases will not be the same, since variations of these quantities are used to express differences in the behavior of the glass as a whole (delayed elastic effect), or in detail at a flaw (breaking strength with time). It is important to note,

(*Continued on page 88*)

ACCIDENT PREVENTION IN THE SMALLER GLASS PLANT

By ERNEST W. FAIR

Many a safety-conscious reader of these pages has studied bulletins and books on safety for his glass plant and then been forced to lay them aside; all treated safety in large institutions only, all specified considerable expenditures as necessary for attainment of the goal and a great many were built around the work of a safety engineer or some other individual whose sole job is the subject of safety in the plant.

Such advice is really of little use since the employment of a safety engineer cannot be supported in the great majority of smaller plants and since in these times of narrow profit margins the plant executive must carefully watch all plant expenses.

With this individual's problems fully in mind we have prepared suggestions adaptable to his small plant and present them herewith; ideas tested in actual practice in small plants and all easily instituted by the glass plant executive himself at little cost.

The first secret of accident prevention in the small plant bears down to the responsibility of its executives; they must know and understand the probable causes of accidents in their own individual plants and then do something to prevent such unsafe practices from actually occuring.

Perhaps it may take him an entire day to study every machine, every location and every operation in his plant as he locates these spots where accidents may occur but it will be a day well spent by the plant executive. Once these have been tabulated in note form, he then has the problem of figuring out how to reduce to an absolute minimum possible occurence.

Tabulation of probable accidents should be broken down into every possible subdivision such as floor, department, section, job, machine, tool, etc., for a much clearer analysis can be prepared if this is done.

On this list for each section he should list the unsafe practices that have caused accidents therein at some time in the past, he should study the operation of each machine in detail and attempt to set down all of the misadventures that could happen in the operation of that machine.

The procedure will be much easier understood if one will bear in mind, while making such investigation, that unless unsafe acts or conditions are located and determined, old as well as new employees can hardly be told what to do or what not to do in order to prevent accidents in the plant. Accident prevention on the part of an employee is chiefly in his knowing what to "look out for" and how to act when the unusual or out-of-routine does occur.

If these factors are then listed under definite groups, such as departments or machines, we can not only more closely study the specific problems therein but we can prepare a much more satisfactory list of recommendations for the employees who work therein.

Another approach is for the executive to put himself in the position of the operator of each machine in his plant; to approach the problem from the angle of all the "wrong things" that could be done in the operation of the machine. Every one of these "wrong things" will make an accident prevention pointer which may save injury to some new worker or which may prevent an old-timer from overlooking something he may have forgotten. Consider just as an example: a) Each of the points where fingers or clothing could easily get caught in that particular machine through carelessness. b) What would happen if someone started the machine without warning; is there protection against this occuring? c) How injury may result through making an adjustment in the wrong manner or at the wrong time. d) Making sure guards are in every spot where they should be and that employees cannot easily remove them.

Thus the basis of the plant executive's accident prevention efforts should be an attempt to locate every possible source of accidents, whether from experience in the plant's past history, his own personal experience, or from some other source. Insurance companies have a great deal of material which they will gladly furnish and the use of such material often helps to keep from overlooking something important.

Naturally, the next step after location and analysis of the possible accident points, is to do something about it. Our safety program should then follow two lines; (1) Correcting all evils that can be immediately corrected, as for example placing a guard around an unguarded spot or erecting stronger guards. (2) Drawing up a code of safety practice for each and every machine, department or section of the plant.

There are always two elements in an accident . . . the machine and the human elements. With the former we can do much but with the latter we can only point out and warn about the dangers. Therefore wise indeed is the plant executive who, if necessary, spends a little money to take the accident probabilities out of machinery and equipment wherever it is possible to do so, who follows safety practices and suggestions as are frequently recommended in this and other industrial journals and who realizes that only a machine well taken care of can help to prevent accidents.

In like manner a single day spent in watching how each employee handles each machine will readily reveal the unsafe practices this employee may be following. Even the best of us get careless and need shaking up once in a while. A friendly talk with that individual, explaining how his continuing to perform such an unsafe practice can easily lead to a specific accident, will get results. And it may well be repeated at least once a year.

"Keep them from forgetting," should be the slogan behind the small glass plant's accident prevention campaign. This can be done by word-of-mouth suggestions at frequent intervals, by bulletins issued from time to time and by posting a safety practice procedure code for each machine right by that machine where the employee must see it day-in and day-out. Never make a mistake so often entered into, i.e., typing the list. Such a notice

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THE MECHANICAL STRENGTH OF GLASS

By W. A. WEYL*

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PART II

IV. Formulation of a Basis for Comparing the Strength of Glass With That of Other Materials

The results of our previous discussion may be summarized as follows: (a) The elementary process of rupture consists of the irreversible separation of atoms or molecules. No other external force but tension can bring about this separation; (b) All solid materials, crystalline, and amorphous, contain flaws. Under tension these flaws act as stress raisers. This is true for internal flaws just as for surface scratches, the latter being more effective. The weakening effect of surface flaws is partly responsible for the erratic strength values which one obtains if specimens of widely differing surface areas are tested. It also accounts for the incompatibility of different testing methods (tension or bending) applied to the same type of specimen. In this case, too, the areas under tension vary in size; (c) A molecular crack cannot propagate through a zone which is in a state of compression; (d) Chemical reactions of the material under test with the environment (moisture of the atmosphere) helps to separate the atoms and speeds up failure; (e) The influence of increasing the temperature on the strength of brittle materials is the result of three independent effects, namely: (1) The weakening of atomic bonds due to increased thermal vibrations, effective over the whole temperature range from absolute zero to the deformation temperature. (2) Release of danger stresses by viscous flow and surface diffusion, the latter increasing the radius of the apex of the flaws. This effect starts at temperatures above 200°C. for soda-lime glasses. (3) Acceleration of the corrosion (chemical reaction of the glass surface with water vapor). This effect becomes noticeable at room temperature but is then strongly reduced above 400°C. where the hydrogen glass becomes unstable, and the bonds broken through the hydrolysis tend to reform; (f) Prestressing the surface under compression increases the tensile strength by making surface flaws ineffective and by delaying or preventing the chemical reactions between the material and the environment.

Keeping these fundamental rules in mind, we shall now look for the conditions under which glasses and other materials can be compared in respect to their mechanical strength properties.

1. The tensile strength of glass as compared with that of organic polymers. Organic compounds are particularly useful in studies concerning the influence of the atomic structure on the properties of matter. They allow us to produce fine variations in the structure and, thus, obtain all possible gradations of a property by replacing one molecular group by another. If one wants to study the mechanical properties of long-chain molecules as a function of the intermolecular forces acting between two chains, organic chemistry offers the wide variation from the rather inert CH_3-groups of rubber to the strong –CO·NH– groups in the hard and brittle urea resins. The variety of bond strengths obtainable by introducing certain side groups is shown in the table below; their cohesion energy is expressed in calories per mol:

		Cohesion Energy
Methylene	$> CH_2$	990 cal./mol
Methyl	$— CH_3$	1700
Chlorine	— Cl	3400
Amine	$— NH_2$	3530
Aldehyde	— CHO	4700
Ester	$— COOCH_3$	5600
Acid	— COOH	8900
Amide	$— CO·NH_2$	13200

The cohesion energy and the space requirements of these groups determine the forces which hold the molecules together. If the groups are large, the chains are kept apart, even if the cohesion forces are strong. The polyvinylacetate resembles rubber more closely than the polyvinyl chloride despite the higher value of the cohesion energy, which is 5600 cal./mol for the acetate group and only 3400 cal./mol for the chlorine.

Increasing the volume of the side groups weakens the bonds and the mechanical strength. This is evident from the softening points of some alkyl methacrylates.

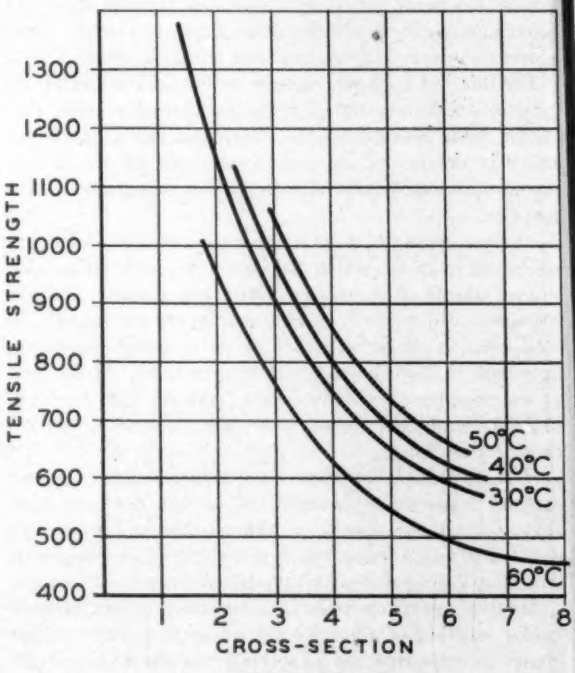

FIGURE 5

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Methyl	methacrylate	125° C.
Ethyl	"	65° C.
n. Propyl	"	38° C.
n. Butyl	"	33° C.
Lauryl	"	Liquid

The space requirements and the intermolecular forces are not only a function of the number of carbon atoms, but also of their spatial arrangement. We must expect, therefore, a change in the mechanical properties if the normal alkyl is replaced by a branched group. In fact, the softening point is raised from 38°C. to 95°C. if the normal propyl is substituted by the isopropyl group.

If we compare molecules of the same shape, and identical side groups, we find that the mechanical strength depends much upon the size of the molecule because the van der Waal forces increase with the size of the molecule. The low molecular weight polystyrenes which are obtained by the use of acid catalysts are brittle, but the same material can be made to a strong, tough resin, if the poylmerization is directed in a way that long chains are formed.

In reality the relation between structure and mechanical properties of high polymers is much more complicated than one would expect from this sketchy outline. The shape of the building units is also very important as one can see by comparing the mechanical properties of rubber and gutta percha. Both polymerized isoprenes may have identical molecular weight, but the different arrangement of the side groups in space makes sliding possible in the case of rubber, but not in the case of gutta percha.

Despite these complications, the organic high polymers represent a field where one can correlate atomic structure, shape and intermolecular forces with mechanical properties, such as softening point, tensile strength or tendency to form fibers. The benefit which one might derive from this field of organic chemistry justifies the effort to become better acquainted with the structure of high polymers. It certainly must be considered a wise move by the British Glass Technologists to have their Society cooperate with the makers of plastics and report in their Journal on the progress made in this field.

The brief outline of the variations possible in the field of high polymers explains the possibility of producing materials which in their strength properties resemble silicate glasses and other substances which behave more like metals.

The increase in tensile strength with decreasing diameter of the fiber which is so typical for silicate glasses has been found also for organic high polymers. Fig. 5 shows the tensile strength of polystyrene fibers of different diameters at various temperatures, according to the measurements of E. Jenckel and P. Lagally.[42]

The most interesting aspect in comparing the strength of glasses with plastics is the influence of temperature, because in this respect the organic compounds show distinctly that they represent a continuous transition between the two extremes, the brittle glasses and the ductile metals.

The fact that natural rosin has its maximum bending strength at 30°C. and is mechanically weaker at both higher and lower temperatures was first reported by F. Hauser (1911).[43] E. Jenckel and P. Lagally,[42] who investigated a polystyrene of the molecular weight 122,500,

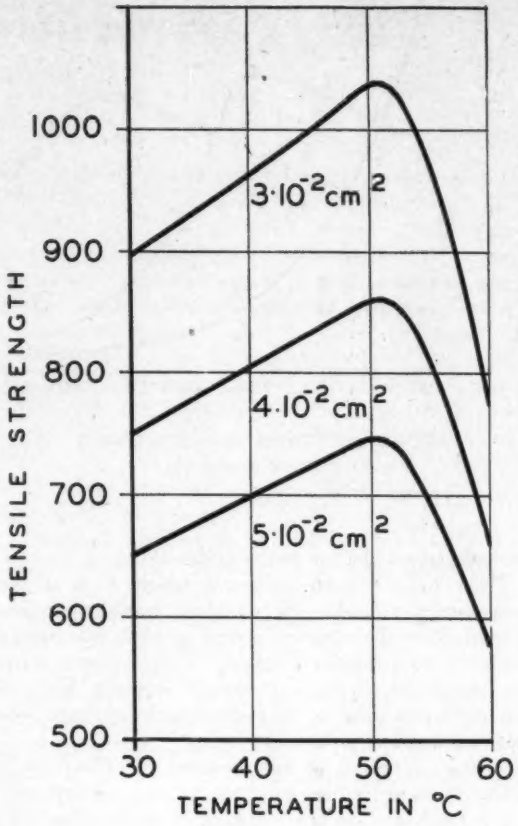


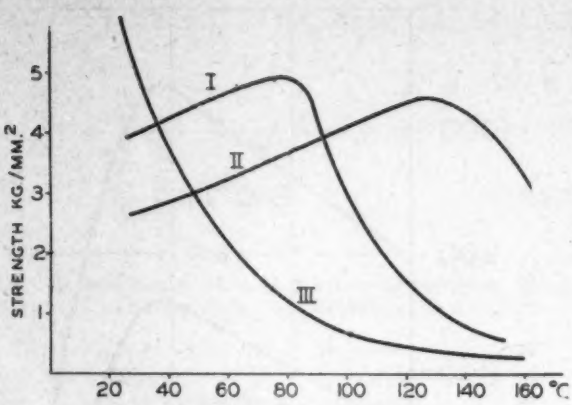
FIGURE 6

found the maximum strength at 50°C. (Fig. 6).

The high molecular weight of this material is responsible for strong intermolecular forces, but also causes the molecules to be so rigidly bound in the structure that they are not free to dissipate the stresses around dangerous flaws. These high molecular resins, whether chains of great lengths, cross linked by strong polar groups, or primary bonds, resemble the silicate glasses in their structure and in their mechanical properties. They are not able to store energy and to yield under high stresses. Their three dimensional bonds make them strong but brittle at room temperature. Like silicate glasses, they gain strength on heating and their fracture takes place without deformation.

If their temperature is raised sufficiently high, their molecular motion permits plastic deformation. They change their strength properties until they approach those of metals and rupture occurs only after necking down to a smaller cross section. This transition from a brittle to a ductile material produces a maximum in the strength vs. temperature curve above room temperature.

S. S. Kistler[44] studied the thermoplastic behavior of linear and three dimensional polymers and correlated the influence of the temperature upon their tensile strength with their chemical constitution. Fig. 7 gives some of his measurements where the maximum of tensile strength is reached above room temperature. Curve I represents the behavior of phenol formaldehyde, Curve II of aniline formaldehyde, and Curve III of a methyl



TENSILE STRENGTH OF RESINS
(AFTER KISTLER)
FIGURE 7

methacrylate-methallyl methacrylate resin.

Those organic high polymers which even at room temperature are able to dissipate maximum stresses around flaws show a steady decline of tensile strength when the temperature is raised. This does not exclude the possibility that their tensile strength also goes through a maximum in the low temperature range, where they are brittle.

Resins of this type are obtained if substances are polymerized to medium long chains with side groups of low polarity and no cross linking by primary valencies.

The lack of three dimensional cross linking makes these polymers "thermoplastic"; they become soft on heating and rigid on cooling. Fig. 8 shows the decline of strength of some thermoplastic resins on heating. S. S. Kistler[44] has selected these resins to demonstrate the influence which the polarity or the cohesion energy of the side groups exert upon the thermoplastic behavior.

Curve I represents the behavior of polyvinyl chloride. Replacing the chlorine by the more spacious acetate group weakens the secondary bond which holds the chains together. Polyvinyl acetate has lost its strength at 40°C. (Curve IV) and co-polymerization of 95% vinyl chloride with only 5% vinylacetate produces a resin with distinctly lower tensile strength (Curve II). Introducing more chlorine atoms has a beneficial effect upon the high temperature strength as is indicated by the behavior of Venalloy (Curve III), a polymerized vinylidenedichloride which stands up even at 160°C.

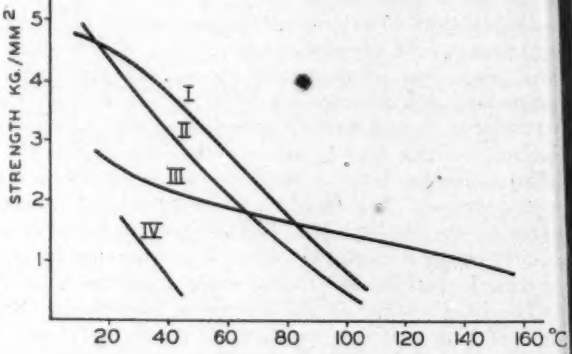
This little excursion into the field of organic materials shows clearly the correlation which exists between structure and strength properties. It shows that glass-like fracture can be obtained if the material is made brittle by three dimensional cross linking. If, on the other hand, the polymerization is directed in a way so as to produce chains which are not cross linked by primary bonds or strongly polar groups, one obtains materials which, like metals, have the possibility of yielding and dissipating dangerous local stresses.

The large variety of building units which the organic chemist has at his command allows him to build resins with a great variety of properties. If ever the occasion should arise for the glass technologist to become interested in the strength properties of glasses of fundamentally different composition, such as borates, borosilicate silicates and alumino phosphates, the structure-streng relationship of organic compounds would form a su able basis for a better understanding of the strength inorganic materials.

The comparison between glasses and plastics in r spect to their strength properties can be extended easil to the influence which the environment exerts. "Chem ical Fatigue" through the reaction with moisture known to exist for organic fibers just as for silica glasses. The great variety of bonds which can exist resins produces materials with widely different acce of humidity.

2. The "Fatigue" of glass as compared with othe "Chemical Fatigue" phenomena. We have seen that th failure of glass under load of long duration is the resul of a chemical reaction which breaks the Si-O-Si bond and, therefore, works in the same direction as the e ternal field of tension. The "Fatigue Test" of glasse or similar materials cannot be considered a mere me chanical phenomenon when carried out in air with th cies toward hydrolysis.

If we want to bring the "fatigue of glass" in line with strength properties of other materials, we have to tes them under comparable conditions. Aluminum, for in stance, is not attacked by the atmosphere, because th dense oxide film which forms prevents further oxida tion. It is well known that under conditions where the



TENSILE STRENGTH OF RESINS
(AFTER KISTLER)
FIGURE 8

oxide film is removed, like in the presence of mercury, aluminum metal reacts even at room temperature with water with the evolution of hydrogen. The salts present in sea water have a similar effect. Therefore, aluminum tested when immersed in sea water gives tensile strength values which decrease with time. The same phenomenon can be observed when other metals are tested under corresponding conditions. The oxidation of copper at room temperature in air is stopped by a thin film of the oxide which must be in a state of considerable compression. In an atmosphere containing ammonia this film is broken up because the copper oxide reacts with ammonia in the presence of moisture. The same is true for some copper alloys. Brass shows

(*Continued on page* 96)

A RUSSIAN HEAT INTERCEPTING GLASS

Heat intercepting or heat absorbing glasses are used for a variety of purposes, e.g., for skylights, window panes, floodlight covers, for protection of cinema films and photocells, etc. Some of these applications require the whole mechanical and chemical endurance usually associated with glass, but some others demand a high transparency for visible light more than anything else. Correspondingly, two types of heat intercepting glass have been worked out in Russia.

The older type comprises silicate glasses and is similar to those ("Aclo," "Calorex") used in U.S.A. and in Britain. Its mechanical and chemical qualities are very high but it has two disadvantages. (1) It is difficult to make plates of this glass without air bells and striae. (2) The glass holds back too much of the visible light; a plate 1 mm. (0.04 inch) thick absorbs and reflects 40 per cent to 52 per cent of the incident light.

The new glasses are phosphates, not silicates. N. V. Golubeva and I. M. Prok, *Russ. Journal of Applied Chemistry 17*, 422, 1944, describe attempts to determine the best composition of a heat intercepting phosphate.

In silicates and borosilicates ferrous oxide is the component employed to reduce the transparency in the infrared. It is resorted to also in the phosphate glasses. However, iron phosphates are not sufficiently heat resistant and also otherwise not satisfactory. Better results are obtained with aluminum phosphate containing only the necessary amount of iron. A systematic study of aluminum-iron phosphate glasses has shown that the composition P_2O_5 78.7, Al_2O_3 19.6, FeO 1.7 per cent had the best chemical endurance. This glass has a slight greenish-bluish tint. Its specific gravity is 2.6. Its softening point is near 770-780° C (1420-1440° F). Devitrification starts at 740° C (1360° F). A polished surface of this glass kept for 48 hours at a relative humidity of 100 percent showed no loss of gloss.

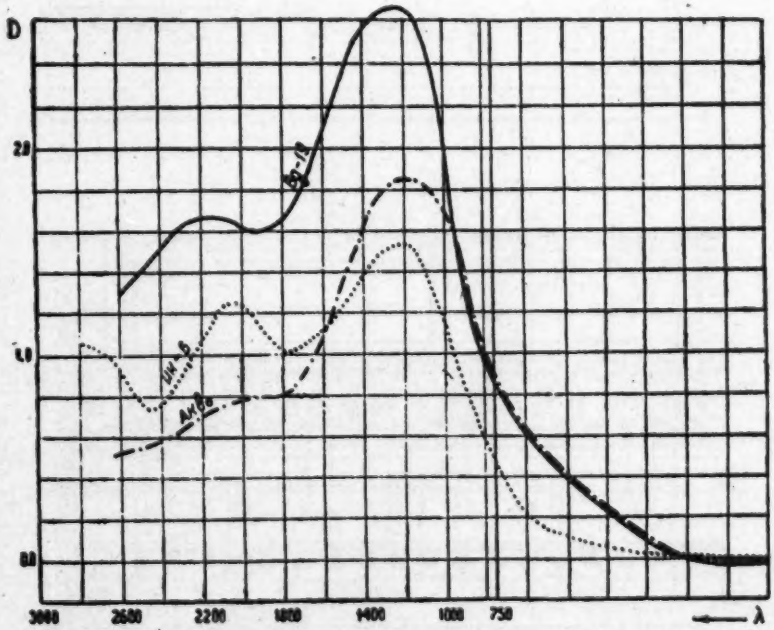
Golubeva and Prok endeavored to produce this glass on a larger scale. The source of alumina was aluminum hydroxide which reacted better than dry alumina. Iron was introduced as pure ferric oxide. For its reduction some carbon was added to the batch. The atmosphere in the furnace was kept strongly reducing. A difficulty was encountered when introducing phosphorus pentoxide. Two raw materials were tested, aluminum metaphosphate $Al(PO_3)_3$ and ammonium dihydrogen phosphate $NH_4H_2PO_4$. When the theoretical amount of aluminum metaphosphate was used the glass contained P_2O_5 75.85, Al_2O_3 21.07, Fe_2O_3 1.75, SiO_2 0.94 and had the refractive index for Na light n = 1.5319. The theoretical amount of ammonium dihydrogen phosphate gave a glass containing P_2O_5 70.84, Al_2O_3 24.53, Fe_2O_3 2.09 and had n = 1.5142. Golubeva and Prok attempted to raise the phosphorus content of the finished glass by using batches containing an excess of ammonium dihydrogen phosphate, but the excess seemed to evaporate since the percentage of P_2O_5 in the finished glass never reached even 76 per cent.

The batch was fed in briquette form to reduce vaporization. The temperature of the furnace vault was 1450°C (2640°F) during the introduction of the batch. For the fining operation the temperature was raised to 1500°C (2730°F). The fining took place readily since the batch used evolved large volumes of gas. Stirring, if required, also was easy.

The glass was cast at 1450°C (2640°F). Casting at 1280°C (2340°F) resulted in a rapid devitrification. The best temperature for annealing was 650°-680°C (1200°-1260°F); glass annealed at 730°-750°C (1350°-1380°F) was found discolored. The glass was "short" and difficult to blow.

The main advantage of this glass was its high degree of transparency for visible light. Plates 1 mm (0.04 inch) thick absorbed and reflected only 14-15 per cent of the incident light. The absorption coefficient of this glass, which has received the designation IK-6, was compared with that of an American heat intercepting silicate glass. At the wave length of 1.5μ both absorption coefficients were equal. Between 1.5 and 2.8μ IK-6 absorbed by, say, 10 per cent more light than did the silicate glass of the same thickness. At the wave lengths below 1.5μ the silicate glass absorbed more strongly

(*Continued on page* 91)



Absorption in infrared by a 3mm. thick layer. λ is measured in mμ i.e. 10^{-7} cm. "Aklo" means a Corning heat intercepting glass. "Uk-6" is the new glass described by Golubeva and Prok. "Bg-19" is a Schott glass.

INVENTIONS AND INVENTORS

A Summary of Recently Issued Patents of Interest to the Glass Industry

Feeding and Forming

A patent to David E. Gray, No. 2,391,963, and assigned to Corning Glass Works, is shown in Fig 1. This machine has some resemblance to the Corning 399 machine but it is fed by a gob feeder instead of a continuous ribbon.

A drum 11 carries a series of parison molds 12, there being neck plungers within the drum adapted to project through neck rings 14 into the parison molds.

The neck rings are carried on an endless conveyor 20 which passes around the axis of the drum 11. While each neck ring is positioned with relation to its parison mold, the mold is closed and a charge of glass is received therein from a feeder 10 of the usual type. Top members 16 then close and the plunger is projected so as to form a parison 35 which depends from its neck ring 14 as the neck ring leaves the parison mold which has been opened. The parison is then carried along in contact with a blowhead 36 carried by an endless conveyor 37. Air is supplied to the blowhead from an air box 39 by which the parisons are puff blown.

Shortly thereafter bottom plates 45 carried on an endless conveyor 46 arrive under the parisons and travel therewith. Blowmolds 52 carried by another endless conveyer soon thereafter close about the neck rings and bottom plates and the finished bottle is blown by air from a blow box 47. The blow molds are then opened, the neck ring releases the bottle and it is carried away on the bottom plates 45 from which it is removed.

It will be apparent that the machine comprises a drum 11 carrying the parison molds and four endless conveyors carrying (1) neck rings 14, (2) blowheads 36, (3) bottom plates 45, and (4) blowmolds 52, all of which cooperate in proper timed relation to receive charges from the feeder and to form them into bottles.

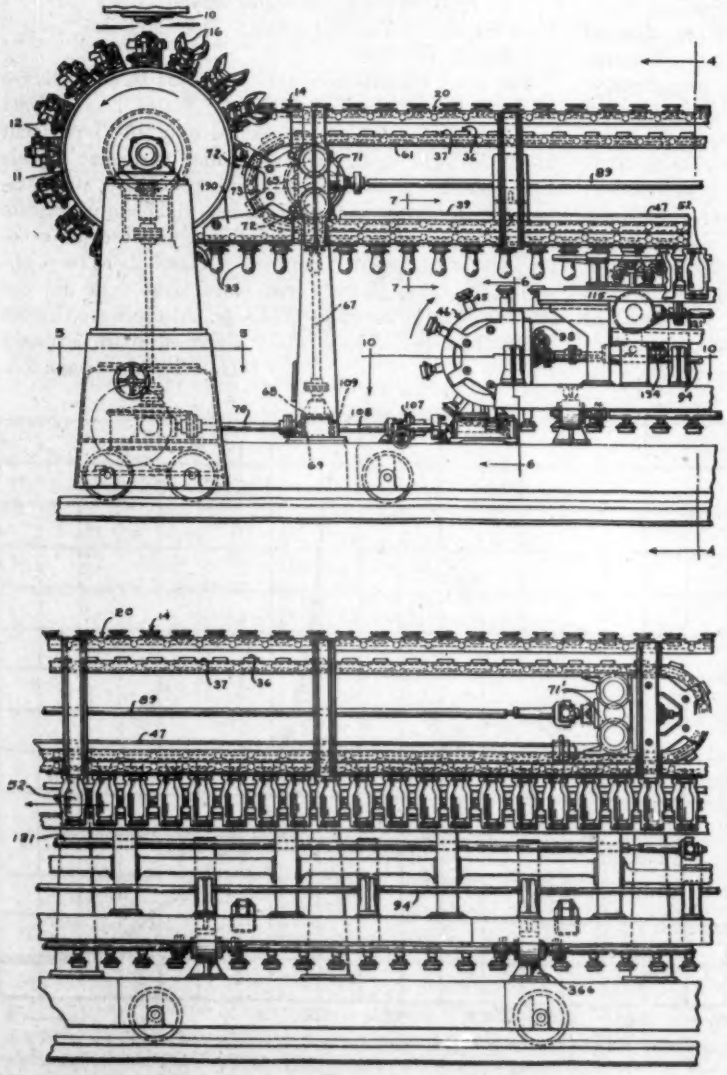


Fig. 1—Corning Chain Bottle Machine, Pat. No. 2,391,963.

Miscellaneous

Norbert S. Garbisch of Butler, Pennsylvania, who is well known for his research in the utilization of waste products from plate glass grinding operations, is the owner of patent No. 2,392,568, assigned to him by George J. Bair. This patent is directed to the manufacture of artificial silicious products which may be used as substitutes for the ordinary ceramic wares. This product is said to be highly resistant to chemical and physical attack and to have great mechanical strength. This patent is a continuation in part of an earlier Bair application, now issued as Patent No. 2,247,270. The distinguishing characteristic of this patent is that the material is subjected to a series of impacts or hammer-like blows while properly heated in a mold.

The apparatus for carrying out this process is shown in longitudinal section in Fig. 2. The waste from the grinding operation, which has formerly been considered not only worthless but a serious nuisance, is fed in measured quantities from a hopper 38 to a series of molds 36, which are intermittently moved through a heated tunnel 28. Suitable burners are provided to heat the tunel and a temperature of 1600 to 1700° F is recommended. The molds are advanced by a pneumatic piston and cylinder indicated at 48.

The heated material is compacted by a press 61, which is reciprocated vertically by a piston and cylinder 67.

In order to provide a hammering effect upon the press head 95, an electrical hammer device 87 is provided to give a series of rapid blows to the press head 95. Thus, by proper heat control to provide a temperature slightly above the sintering point of the glass content of the waste material and below the sintering point of the silica content, a strong dense body is produced.

The formed blocks are removed from the molds at an unloading platform 126 and placed on a conveyor 127 running through a second tunnel 129, where they may be reheated for glazing or annealed to remove any possible internal strains.

Patent No. 2,392,099 issued on the application of Charles E. Pollard, Jr., has been assigned to Bell Telephone Laboratories. This patent relates to annealing and chemically cleaning glass as used in electrical apparatus. It is especially adapted for use in making what is known as the Ellwood unit shown in Patent No. 2,289,830. Extreme accuracy is necessary in assembling these units in order to obtain a satisfactory product.

It has been the former practice to remove extraneous matter from electronic apparatus by heating the parts in a partial vacuum or in an atmosphere of hydrogen.

In this patent it is proposed to anneal and clean the glass and other parts of the apparatus by heat treating in an atmosphere of purified hydrogen at a temperature of about 420°C which can be done in one operation.

Fig. 3 shows an enlarged section of a completed unit made by this process. The various parts are clearly labeled in the drawing.

Fig. 4 shows the Anchor Hocking lehr loader or stacker which is of the pushbar type. It is the invention of William L. McNamara and James McFee. The object of the invention is to provide a stacker of this type which will be readily adjustable to handle ware of different sizes and shapes and which will be mainly operated by mechanical means so as to avoid the high cost of air operated mechanism.

Articles come from the forming machine on the usual conveyer from which they are automatically transferred to a cross conveyor extending across the front of the lehr. Suitable mechanism is provided so that the cross conveyor can receive ware from either end, thus providing a right or left delivery to the lehr.

As shown in Fig. 4, the lehr 5 has a conveyor 6 onto which the ware is pushed by a bar 106. The cross conveyor 14 brings in a line of properly spaced ware as determined by a spotter wheel 45 which can be arranged to take ware from either end of the cross conveyor, this conveyor being adjustable to travel in either direction. The support for the cross conveyor 14 is made up of an angle iron structure comprising the parts 11, 12 and 13. A plate 104 bridges the gap between the conveyor 14 and the lehr conveyor 6.

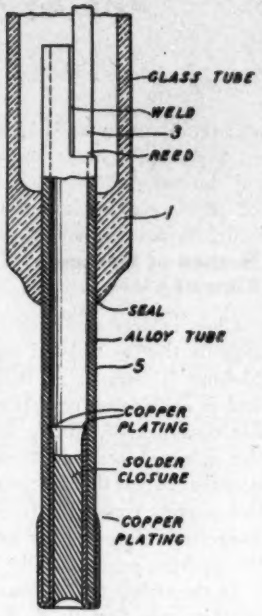


Fig. 3—Method of Making Sealed Glass Units, Pat. No. 2,392,099.

The push bar 106 is carried on adjustable straps 108 and 109 by which the vertical position of the bar may be suited to the ware being handled. These straps are carried by a cross shaft 111 having grooved rollers 113 at each end which on the forward stroke, ride on tracks 114 lifting the track sections 119. These tracks guide the push-bar in pushing the ware into the lehr. On the idle return stroke, the rollers 113 ride up on the tracks 119 and 118 and then drop downwardly into position behind the oncoming line of ware, ready for the next stroke. The travel of the rollers 113 is shown in dotted lines in the upper part of the figure. Rearward movement of the push bar 106 is prevented by adjustable screws 123. The path of the push bar is indicated by the line of arrows in the lower part of the figure. Various adjustments not mentioned are provided to give complete control of the lehr loader.

This patent was assigned to Corning Glass Co. by Robert H. Dalton. The patent relates particularly to hermetic glass seals with metals such as molybdenum and alloys of iron, nickel, and cobalt such, for example, as the alloy known as "Fernico" comprising 54% Fe, 28% Ni, and 18% Co. It is essential that glass for such purposes shall have the proper expansion, chemical durability, electrical resistance and workability.

The glass proposed in this patent is set forth in Claim 1 of the patent as follows:

A glass of high electrical resistiv-

(*Continued on page* 102)

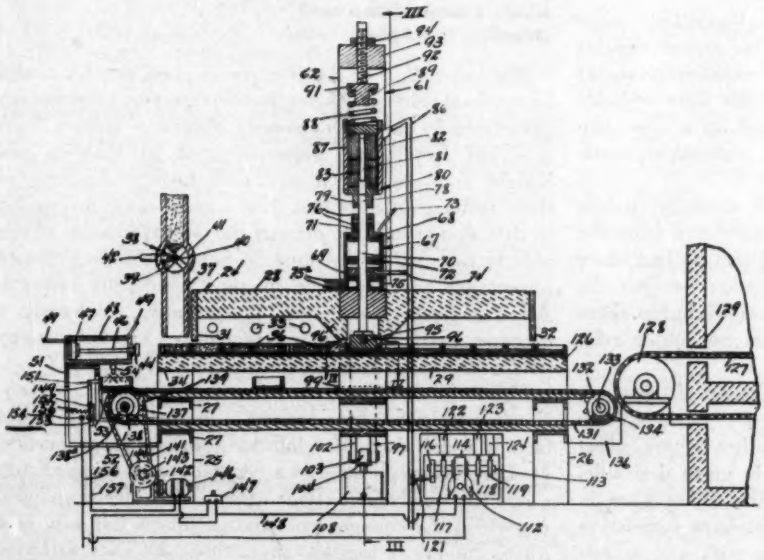


Fig. 2—Method of Utilizing Waste from Plate Glass Grinding, Pat. No. 2,392,568.

GI Research Digest

Practical Interpretations of Glass Technology

Method of Measuring Fining Time of Glass

Glass is produced from a mixture of crystalline materials by the two related processes of melting and fining. Melting is defined as the formation of a liquid phase and is considered complete when all crystalline material has disappeared. Fining is defined as the elimination of the gases of reaction from the melt and is considered complete when the melt no longer contains bubbles. The two operate concurrently but fining always continues for some time after melting has ceased. Fining is, therefore, the limiting process in the making of glass.

In the October 1945 issue of the *Journal of the American Ceramic Society*, A. K. Lyle describes a method for determining the fining time of glass and demonstrates its usefulness in estimating the fining rates of glasses melted in continuous furnaces. In brief, the method used is as follows: Under carefully controlled conditions, a small charge of pulverized batch is added to a platinum crucible containing a relatively large amount of previously melted and fined glass. At the end of a predetermined interval of time, a sample is poured from the crucible. When annealed and cooled, the sample is examined for bubbles. The fining time is noted as the minimum time required to produce a sample substantially free of bubbles as determined by a series of tests. The temperature range used varied from 1400° to 1500° C. Fining times ranging from 15 to 250 minutes have been determined with satisfactory precision. At 1475°C., the results obtained in tests of commercial glasess may be expected to lie between 25 and 75 minutes and at 1425°C., between 100 and 250 minutes.

If the fining times are plotted on a logarithmic scale against temperature on a scale of reciprocal degrees Kelvin, straight lines give satisfactory representations of the data and the random pattern of the lines indicate that the fining time must be determined for at least two temperatures and preferably three, if accurate comparisons between glasses are to be made.

From a plot of fining time against viscosity, it was shown that fining times could not be predicted from the results of viscosity measurements and that at best there exists no more than a general correlation between the two properties. Likewise, a comparison of fining times and surface tension data indicates that no simple relationship was evident.

The viscosity, surface tension and density of the glass, the solubilities and the relative amounts of various gases in the batch and glass, and no doubt other factors, affect the process of fining. Therefore, it is more desirable, from practical considerations, to define fining time in terms of a test method than it is to attempt correlation of the fining characteristics of glasses with one or two physical properties. It is essential, however, that the results obtained by the test be capable of practical interpretation.

A comparison of fining times with data from continuous furnaces showed that the fining time could be correlated directly with the ratio of melting area to tons of glass produced. The fining rate of a glass in a continuous furnace may be calculated from fining-time data by the use of equations (1) and (2).

$$A = 0.065F + 3.25 \qquad (1)$$

$$tc = 1.02t_f + 5 \qquad (2)$$

A = melting area-tonnage ratio (sq. ft./ton/day).
F = fining time (minutes).
tc = continuous furnace temperature °C. (bridgewall).
t_f = laboratory furnace temperature °C.

The data given by Lyle were taken from tests of colorless glasses, and the correlations established apply to furnaces supplying glass for the manufacture of containers. The method can be used without modification for all types of glass except carbon-sulphur ambers and other glasses containing reducing agents in the batch. As the design of window and plate glass furnaces is different from container glass furnaces and the relative importance of bubbles is different in the two types of glass, it is unlikely that a single correlation formula would apply to all manufacturing conditions. A special formula should, therefore, be developed for each type of operation.

Other suggested uses for this method of measuring fining time include: 1) The study of the effectiveness of fining agents and 2) the investigation of the influence of composition on fining time.

Glass Composition and Density Changes

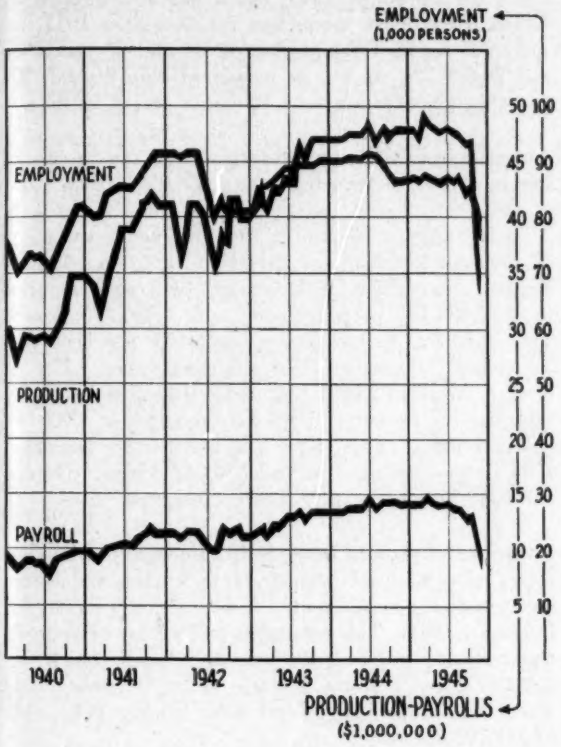
The calculation of the changes in glass density caused by moderate changes in composition may be conveniently performed by the use of density difference factors. Such a set of factors has been proposed by Ghering and Knight and are known as "Ym" factors. Analysis of these factors indicates that they may be quite misleading as they do not indicate directly the density change ascribable to each oxide and thus do not indicate the relative importance of each oxide in affecting density changes. All Ym factors, moreover, are negative, indicating a decrease in density for an increasing amount of any oxide; this is not in accord with known facts.

Elliot (*Journal of the American Ceramic Society*, November 1945) has derived a more rational set of factors which have the following desirable properties: 1) They are applicable to a general composition change where the weight percentage of several oxides is changed (provided the changes are small); this is the only case where the Ym factors are applicable. 2) They will give

(*Continued on page* 86)

CURRENT STATISTICAL POSITION OF GLASS

THE GLASS INDUSTRY'S INDEX



Activity in the glass industry during November 1945 was shown in the Production Index to be $34,750,000—a drop of about 25 per cent from the figure reported for October. November 1944 production was $48,000,000, which is about 21 per cent more than for November 1945. Output for the January-November 1945 period totals $500,550,000 as compared with $524,000,000 during the same period in 1944.

Employment and payrolls: The total number of persons employed in the glass industry during November 1945 was 76,800. For the month of October 1945, reports showed the employment of 86,600 persons and for November 1944, the total was 87,100.

Payrolls for November 1945 were $9,500,000, an approximate 25 per cent drop from the $12,600,000 reported for October 1945. Payrolls for November 1944 were about 34 per cent over November 1945, or $14,500,000. During the first eleven months of 1945, glass container manufacturers paid out about $141,555,000 in salaries in comparison with $156,250,000 paid out during the same period in 1944.

Glass container production for the month of December 1945, based on figures released by the Bureau of Census, was 8,604,979 gross which is approximately 3 per cent under figures for November 1945 which were reported to be 8,902,491 gross. Production for December 1944 was 7,667,404 gross, or about 12 per cent less than for December 1945. Total production for the year 1945 was 105,368,925 gross in comparison with 99,726,927 gross produced during 1944. This is an approximate difference of 12 per cent.

Shipments of glass containers during December 1945 were reported at 8,107,248 gross; for November 1945, they were 8,902,491 gross—a difference of about 8 per cent. Shipments during December 1944 were about 9 per cent under December 1945, or 7,389,949 gross. Total shipments made during 1945 were 106,653,861 gross and about 10 per cent over 1944's total shipments of 96,385,087 gross.

Inventories on glass containers for December 1945 were 4,328,458 gross, indicating a rise of about 12 per

GLASS CONTAINER PRODUCTION AND INVENTORY

(All figures in gross)

		Production Dec., 1945	*Stocks Dec., 1945*
Foods; Medicinal & Health Supplies; Chemicals, Household, Industrials; Toiletries & Cosmetics	Narrow Neck	2,834,149	1,916,548
	Wide Mouth ...	3,028,586	1,103,204
Dairy Products		323,968	173,304
Home Canning		109,082	361,629
Beverages, Returnable		498,942	330,470
Beverages, Non-returnable			
Beer, Returnable		412,858	71,562
Beer, Non-returnable		162,760	31,043
Liquors		900,468	243,257
Wines		255,472	85,344
Packers' Tumblers		78,694	12,097
Total		8,604,979	4,328,458

GLASS CONTAINER SHIPMENTS

(All figures in gross)

Narrow Neck Containers	*Dec., 1945*
Foods	561,293
Medicinal & Health Supplies	951,239
Chemical, Household, Industrials	547,501
Beverages, Returnable	466,650
Beverages, Non-returnable	
Beer, Returnable	393,771
Beer, Non-returnable	169,846
Liquors	845,741
Wines	240,965
Toiletries & Cosmetics	477,501
Sub-Total (Narrow)	4,654,507
Wide Mouth Containers	
Foods	2,460,488
Dairy Products	307,267
Home Canning	33,971
Medicinal & Health Supplies	209,418
Chemical, Household, Industrials	99,593
Toiletries & Cosmetics	134,535
Packers' Tumblers	73,446
Sub-Total (Wide Mouth)	3,318,718
Total Domestic	7,973,225
Export Shipments	134,023
Total Shipments	8,107,248

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cent over November 1945 inventories and 14 per cent under December 1944.

Plate glass production for the month of December 1945 was again influenced by strikes in the industry and the Hughes Statistical Bureau reports production to be 429,389 sq. ft. This is a little lower than the production figure for November 1945, which was also affected by strikes. Plate glass production for December 1944 was 7,012,983 sq. ft. Total production during the year 1945 was 84,589,324 sq. ft., as compared with 101,937,701 sq. ft. produced during the 12-month period in 1944.

Automatic tumbler production for the month of December 1945 is reported to be 5,250,035 dozens. This is about 8 per cent less than the November figure of 5,721,966 dozens. December 1944 production was about 18 per cent less than for December 1945, or 4,430,514 dozens. Shipments for December 1945 were reported to be 5,493,136 in comparison with 4,495,220 dozens. This indicates an increase of about 11 per cent over November. December 1944 shipments were 4,378,763 dozens—or about 25 per cent under December 1945. Inventories for December 1945 were reported at 4,900,884 dozens which is about 16 per cent less than for December 1944 inventories which were 5,879,013 dozens. November 1945 inventories were 5,869,860 dozens.

Table, kitchen and household glassware: Manufacturers' sales of machine-made table, kitchen and household glassware were reported to be 2,919,199 dozens for December 1945. This represents an increase of approximately 8 per cent over the preceding month which was 2,684,177, and a slight decrease under December 1944 which was 2,928,552. Total sales during 1945 were 32,211,793 dozens.

CHICAGO SECTION PLANS JOINT MEETING

A joint meeting of the Chicago District Enamelers Club and the Chicago Section of the American Ceramic Society will be held on February 23 at the LaSalle Hotel. Charles Pearce, Associate Secretary of A.C.S., is to speak and regular meetings of each group will be held after the luncheon meeting.

The program will include a talk on the principles and application of the Betatron by Professor Almy of the Physics Department at the University of Illinois, after which Professor Mursh of the Department of Ceramic Engineering will present several of the specific details involved in the development of the special whiteware body which forms the integral core of the Betatron. In addition, N. S. Debanhas, research engineer of the Carnegie Illinois Steel Corporation, will present a timely paper on recent research and development in refractories.

● Francis R. Parady has recently joined the O. Hommel Company as sales representative. Mr. Parady was formerly enameling superintendent for the Florence Stove Company and, most recently, served with the United States Navy. He will serve the Eastern States.

HAHNER OF BUREAU OF STANDARDS REPORTS ON TRIP TO GERMANY

In a recent statement issued by the Department of Commerce, it was pointed out that optical glass produced by the National Bureau of Standards and by private American manufacturers is of as high quality as any optical glass made in Germany and that the United States will never again have to look to any foreign source for such products.

C. H. Hahner, head of the Glass Section of the Bureau of Standards who has recently completed an inspection of German plants for the Army Ordnance Department, stated with respect to his inspection of some of the Zeiss operations: "In some lines we are away ahead of the Schott firm, a subsidiary of the Zeiss company which controlled all German optical glass production" and that "one American company is now turning out optical glass of a type the Zeiss people never have approached."

Asked whether the Germans could make better glass than is now being made here, Mr. Hahner said: "There is always room for improvement. I would not say the Germans could not make better glass than we are turning out but that they are not doing so. I might add that we also could make better glass than we are now producing, if necessary, and doubtless will do so provided adequate provision is made for continuous research in this important field."

In reply to further questions, Mr. Hahner said that the Schott plants turn out a greater variety of optical glass than American companies but that some German types are so close together as to amount almost to duplication. For example, within a given range Schott may have 14 or 15 glasses. For the same range United States producers probably would not have more than 4 or 5, thus avoiding an approach to duplication.

Touching on comparative methods of melting operations, Mr. Hahner pointed out that some costly rare earths used in optical glass manufacture cannot be melted in the clay pots customarily used for this purpose because their reactions would dissolve the pots. Platinum-lined pots are used in the United States for handling these materials. Mr. Hahner saw no platinum-lined pots in the plants visited in Germany and suggested that a shortage of platinum may have discouraged its use there.

"The Germans pioneered in the optical glass field," said Mr. Hahner. "The French also did some pioneering, but with the work of Schott and Abbe the Germans went much further, setting the general pattern. In the early stages of production in this country we largely followed German practice. During the past ten years or so, however, we have broken away from the German pattern and struck out on independent lines."

The National Bureau of Standards has been producing optical glass for the Government since World War I when the United States was cut off from supplies normally received from Europe. During the interim period between World War I and II the Navy provided funds for research and for manufacture on a modest scale. With the advent of World War II the Bureau plant was greatly expanded. Production reached a monthly high of 30,000 pounds. During its best full year of operations this plant turned out approximately 240,000 pounds of high grade optical glass. This was only a small part of total United States production which ran into millions of pounds during each wartime year.

In reply to a question concerning the yield in optical glass manufacture, Mr. Hahner said that, unfortunately, the yield is low and always has been. Only about 25 per cent of the materials used are recovered in the form of the highest grade glass. However, the rate in Germany, longest in the field by many years, is approximately the same.

The Bureau's plant has done considerable research on the problem of continuous process production of optical glass, Mr. Hahner added. Solution of this problem would do away with the laborious process of cooling the glass in pots, breaking it out, reworking and the like, largely reducing production costs.

Mr. Hahner and his associates are now analyzing some ten tons of optical glass recovered by the United States Navy from a German submarine captured while enroute to Japan. About 25 per cent of this glass has been examined to date. Indications are that rejects may reach 40 per cent. This, in turn indicates that the Germans were not sending their best optical glass to their Japanese allies.

Records examined in one German plant on his recent visit satisfied Mr. Hahner that even misleading information was sent to the Japanese. There was nothing to indicate that this was official Government policy, but it very definitely was the policy of that particular plant.

During the air blitz of England the Bureau of Standards made available to Canada and Australia all data necessary to enable them to start producing optical glass as a precautionary measure in the event that English plants might suffer damage from bombing. Similar assistance also was given American glass manufacturers who desired to enter the optical glass field as a contribution to the war effort when the demand from our armed forces was greatest.

UHRMANN ASKS FOR HELP IN GERMANY

In a cablegram addressed to the Joint Intelligence Objectives Agency under whose auspices Carl J. Uhrmann is conducting his studies of German glass plants, he has urged the assignment of another investigator to help complete this important work.

In connection with this request, H. L. Dillingham, Business Manager of the American Glassware Association, has urged his membership to contribute to a fund which is required for the continuation of these investigators since the original Government appropriation has become exhausted and Congress feels that industry should partially finance the work.

In his bulletin, Mr. Dillingham emphasized that if only comparatively small amounts are contributed by each company in the entire glass industry, the cost of sending another investigator to Europe can easily be defrayed and industry will benefit many fold by the results obtained.

• An increase of 2½ per cent in manufacturers' ceilings for rough-rolled, figured, wire and heat-absorbing rolled glass was announced by the Office of Price Administration last month. The action became effective January 14, 1946.

"SCOTCHLITE"—NEW REFLECTIVE MATERIAL

A new reflective material, known as "Scotchlite," is being manufactured by the Minnesota Mining and Manufacturing Company.

The new material, consisting of many tiny glass

spheres in minute form held to a backing by a specially developed adhesive, is particularly adapted to outdoor advertising signs, warning signs, signal markers and countless other uses.

As a safety measure, the reflective quality of "Scotchlite" is of great advantage. Warning signs and road markers remain visible not only at night, but retain colors both day and night. Ease of application, flexibility and weather resistant properties all contribute to the product's possibilities.

Illustrated above is a large truck reflectorized with "Scotchlite" as it appears in daytime and nighttime.

PITTSBURGH SECTION FEBRUARY MEETING

The February meeting of the Pittsburgh Section of the American Ceramic Society is scheduled to be held on February 12 at the Mellon Institute auditorium.

The evening's program will include at talk by Dr. Rose, Executive Vice President of Bituminous Coal Research, Inc., on the subject "Glimpses of Western Germany, Summer, 1945". His talk will be illustrated by color and black and white film.

Dr. Phelps, Senior Fellow of the Refractories Fellowship of the American Refractories Institute, will give a paper entitled, "Comments on the German Refractories Industry during the War". The subject matter will relate primarily to fire clay, silica, basic and carbon refractories, as well as comments on plants and equipment.

LACLEDE-CHRISTY EXPANDS

Laclede-Christy Clay Products Company, St. Louis, Missouri, has announced the purchase of the properties and business of the Alabama Clay Products, Birmingham, Alabama. These properties will continue to be operated as the Alabama Clay Products Company, a wholly owned subsidiary of Laclede-Christy.

In 1931, Laclede-Christy acquired the Buckeye Clay Pot Company, which is now one of the three large plants operating in St. Louis and Toledo.

A. S. Holberg, President of Alabama Clay Products Company will continue with the organization, and H. W. Gethin, formerly Manager of the Pittsburgh District of Laclede, will be Vice President and General Manager of the newly acquired Alabama company.

LIBBEY SPONSORS ERNIE PYLE BOOKLET

From material written by Ernie Pyle on the art of glassmaking and which was originally presented in five columns written by Mr. Pyle in 1941, Libbey Glass Division of the Owens-Illinois Glass Company has sponsored a private printing in booklet form of these columns entitled, "Ernie Pyle on Glass".

The columns by Ernie Pyle were written after he had made a visit to Toledo and the Libbey Glass plant and gives his impressions on glass making. A number of photographs are included showing Ernie Pyle "trying his hand" at some of the steps necessary in making glass.

CORNING APPOINTMENTS ANNOUNCED

J. Norman Reilly has been named as Assistant to the President according to a recent announcement made by Corning Glass Works. Mr. Reilly was formerly Assistant Manager of Corning's Bulb and Tubing and Technical Products Divisions.

In his new post, Mr. Reilly will have charge of long-range production planning and coordination of all manufacturing facilities and schedules at the company's plants in New York, Pennsylvania, Rhode Island and West Virginia. Mr. Reilly has been associated with the company for the past 32 years.

At the same time, Corning Glass Works made known that Howard E. Bahr is rejoining the company as Manager of the Public Relations department after four years' military service.

Mr. Bahr, who has been with Corning since 1934, will be responsible for institutional advertising, company publications, preparation and distribution of product exhibits and all general publicity of company operations for newspapers and the trade press.

CHAS. TAYLOR SONS APPOINTS SALES REPRESENTATIVE

The appointment of J. B. Hayes Company, Birmingham, Alabama, has been announced by Chas. Taylor Sons Company of Cincinnati, Ohio. The Hayes Company will be their exclusive sales representative in Alabama and the adjoining territory.

Mr. Hayes has been closely associated with the industrial development of the South and Southwest for the past twelve years, specializing in the sale and application of carbon and graphite products in electric steel foundries and allied industries. The acquisition of the complete line of Fire Clay, P. B. Sillimanite and Zircon refractories manufactured by Chas. Taylor Sons Company now enables Mr. Hayes to offer a complete refractories service to consumers in the South and Southwest.

RUTGERS CERAMIC CLUB HOLDS MEETING

The Rutgers Ceramic Club and Student Branch of the American Ceramic Society held its January meeting at Rutgers University, New Brunswick, New Jersey.

Guest speaker for the evening was Dr. Campbell Robertson of E. I. du Pont de Nemours & Company, Inc., whose subject was "Ceramic Color Applications."

AMERICAN GLASSWARE ELECTS BOARD OF GOVERNORS

The American Glassware Association has recently elected the following Board of Governors for the year 1946.

Delegates at Large, Bernard E. Factor, Vice President, Anchor Hocking Glass Corporation; Calvin B. Roe, Chairman of Board, Fostoria Glass Company. Alternate at Large, Charles L. Gaunt, President and General Manager, Indiana Glass Company.

Division representatives were elected as follows: Division "A", Illuminating, Charles W. Gleason, Vice President, Gleason-Tiebout Glass Company; Division "C", Lamp Chimney, Robert L. Straub, Secretary-Treasurer, Cameron Glass & Mfg. Company; Division "E", Automatic Machine Made, J. N. McNash, Sales Manager, Tableware Division, Hazel-Atlas Glass Company; and Division "H", Hand Made, Charles W. Carlson, President, United States Glass Company.

An organization meeting for the new Board of Governors is planned for the near future.

JESSOP STEEL ELECTS PRESIDENT

Fred T. H. Youngman, formerly executive vice president, has been elected president of the Jessop Steel Company. Mr. Youngman succeeds R. Edson Emery, who was made chairman of the board.

Mr. Youngman has been associated with the Jessop Steel Company for the past 25 years and has held the offices of secretary and treasurer, first vice president and executive vice president.

At the same time, three new directors were added to the Jessop Steel board of directors. They were W. C. Buchanan, president of the Globe Steel Tubes Company; Andrew J. Dallstream, Pam, Hurd & Reichman; and Linwood A. Miller.

The company contemplates expansion of its facilities in the near future.

COLUMBIA CHEMICAL MAKES APPOINTMENTS

Columbia Chemical Division of the Pittsburgh Plate Glass Company recently announced the appointment of Joseph A. Neubauer to the post of technical advisor, with headquarters in the general office at Pittsburgh, Pa.

Mr. Neubauer was previously superintendent of the chlorine producing works at Natrium, West Virginia, and has recently returned from a three-months' mission to Germany where he represented the government's Technical and Industrial Intelligence Committee, a function of the Foreign Economic Administration.

Also announced, was the appointment of Earl Wolf as superintendent of the Natrium plant. Mr. Wolf joined the Columbia Chemical Division in 1934 and has most recently served as plant engineer at the West Virginia plant.

HATCH RESIGNS FROM H-E

The resignation of Roswell F. Hatch from the Hartford-Empire Company was made known in a recent announcement.

Mr. Hatch joined Hartford-Empire in 1920 as a patent attorney. The company, at that time, was known as the Hartford Fairmont Company. He has traveled extensively throughout the United States during the past twenty-five years and has a wide acquaintance in the glass industry.

As a farewell gesture on the part of the Hartford-Empire company's employees, Mr. Hatch was given a dinner and was presented with a parting gift as a token of their esteem.

Mr. Hatch has no definite plans for the future but does contemplate making a trip of inspection to Florida before spring.

NEW DU PONT CERAMIC LABORATORY IN COLUMBUS

A general laboratory for service to the ceramics industry will be established in Columbus, Ohio, it was announced recently by the Electrochemicals Department of E. I. Du Pont de Nemours & Co., Inc.

A one-story concrete building, 70 by 100 feet, at Pennsylvania Avenue and Goodale Street, has been leased as headquarters for the Du Pont technical service staff and field representatives covering the entire industry.

Robert Galbraith, Manager of the Ceramic Products Division, said it was expected that the new laboratory would be in operation sometime after March 1. The most modern facilities will be installed and the laboratory will be staffed by about twenty men and women.

O. T. Frasier, field service representative whose headquarters have been in Columbus, will be in charge of the laboratory. Columbus was chosen, it was said, because of its central location in the ceramic industrial area.

BALL BROS. NAMES NEW PLANT MANAGER

At a dinner for plant managers and superintendents of the Ball Brothers Company in Muncie, Indiana, it was announced that Carl Donovan would be the new Plant Manager at Wichita Falls, Texas, effective January 15. The dinner was given by the Ball Management Club.

Officers of the Club were elected. They were Leo J. Hanley, named President, Glenn Crumm, Vice President, and Bert Wallace, Secretary-Treasurer.

John W. Fisher, Glass Factories Manager, announced the adoption of a "glass division training program" and called upon V. J. Cox, director of the training program, to outline the plan's objectives.

Edmund F. Ball, Executive Vice President of the company, also was a speaker on the program.

PILKINGTON BROS. NAMES NEW OFFICER

L. J-B. Forbes has been appointed Vice President and General Manager of Pilkington Bros. (Canada) Ltd., according to a recent announcement.

The announcement was made by W. H. Pilkington, President of Pilkington Glass, Ltd., which is the home office located in London, England. Mr. Pilkington had been in Canada to make a trans-Canada tour.

Mr. Forbes, who came from Scotland, succeeds James E. Harrison who has retired after 54 years with the Company.

PERSONNEL CHANGES AT OWENS

Personnel changes in the sales department of the Glass Container Division of Owens-Illinois Glass Company were announced recently. A. S. McKaim, recently honorably discharged from the Army, has been named acting manager of the newly created Prepared Foods Division.

Joseph W. Parks becomes Manager of the Plastics Division, W. M. Robertson has been named Manager of the Pharmaceutical and Proprietary Division and Arthur Kohl, Manager of the Household and Chemical Products Division.

Lawrence Crossley has been made Manager of the Cleveland branch and Sidney F. Davis, formerly with the Navy, has returned to Chicago to again take over the duties of Branch Manager.

DATE CHANGED FOR CHEMICAL EXPOSITION

The date of the National Chemical Exposition has been moved up to September 10 through 14, 1946, according to a recent announcement by Dr. H. E. Robinson, Chairman of the Exposition Committee.

The Exposition is sponsored by the American Chemical Society and will be managed by Marcus W. Hinson.

ACCIDENT PREVENTION IN THE SMALLER GLASS PLANT . . .

(*Continued from page* 73)

will be read once and no more. But if the suggestions are sharp and to the point without wasted words, and are lettered in big type on a large sign they will "hit" the employee every time his eyes wander that way. And of course such a list should be so spotted that force of habit will draw the employee to it every day; not posted in an out of the way corner.

Experience has also shown that it is better to present each employee with only that part of the suggestions pertaining to his own particular job rather than the whole plant's *code of safety* ideas. The reason is apparent; it is much easier for any of us to remember ten pointers than a hundred. Then too, we will respect and give attention to a list vitally concerning us while on the other hand if 90 per cent of the list does not concern the individual he will give little respect to the whole list.

It is also recommended that every employee be continually made safety conscious by having that employee, at least once a month, check his machine for unsafe conditions. These should be presented on a printed or typewritten card. The employee checks each one, discovers if that condition is apparent and if so then notes this on the card. He then signs and returns this card to the plant manager. This not only helps to keep each and every employee safety conscious but keeps that individual as a watchdog on prevention of the occurance of unsafe conditions on the equipment he uses every day.

Then if we precede this by a list of "things not to do" and "to watch out for" to every new employee we keep the subject of safety uppermost in his or her mind.

And here is a final suggestion . . . no matter how minor the accident, study it closely, seek to determine if there is not some lesson to learn from that accident, some small incorrect condition or practice that corrected immediately can prevent a major accident later.

This procedure requires no financial investment, can easily be handled by any glass plant executive, and is so simple that any employee can be a part of it . . . and for those reasons can well be put into practice by any plant.

RESEARCH DIGEST . . .

(*Continued from page* 80)

directly the density change due to simple dilution. For example, as an increase in batch weight of one component; the Ym factors will not do this. 3) They are small. 4) Their signs and magnitudes indicate directly the density changes ascribable to each oxide in a composition change involving any number of oxides; all of the Ym factors are negative and their magnitudes do not indicate the relative importance of each oxide in affecting the density.

The new factors (Y^1m) are shown in Table I along with those of Ghering and Knight (Ym). They are calculated for a bottle glass of density 2.49 gm. per cc. having a silica content of 66 to 75 per cent. The same factors, however, will apply to a similar glass in the density range of 2.45 to 2.53 with a maximum error of $\pm$ 0.0005 gm. per cc. if the change in composition does not exceed 1 per cent.

TABLE I

FACTORS FOR CALCULATION OF DENSITY DIFFERENCES

Oxide	Density change (gm./cc./%) Ym	Y^1m
SiO_2	—0.0273	—0.0024
Al_2O_3	—0.0232	+0.0018
CaO	—0.0143	+0.0106
MgO	—0.0199	+0.0050
BaO	—0.0075	+0.0173
Na_2O	—0.0200	+0.0050
K_2O	—0.0222	+0.0028
B_2O_3	—0.0281	—0.0036
ZnO	—0.0105	+0.0145
PbO	—0.0056	+0.0192

NEW YORK METROPOLITAN SECTION OF A.C.S. HOLDS SECOND MEETING

On January 23, the second meeting of the New York Metropolitan Section of the American Ceramic Society was held in the Building Trades and Employers Association Building in New York City. Eighty-nine members attended the meeting.

Speakers of the evening were Dr. Ralston Russell, Jr., Director of Ceramic Research at Westinghouse Research Laboratories in East Pittsburgh, Pa. and Rexford Newcomb, Jr., ceramic engineer for Brickseal Refractory Company in Hoboken, New Jersey.

In his talk, Dr. Russell related some of his observations on the technical and electrical porcelain industries in Germany where he spent two months on a government assignment.

Rex Newcomb discussed high temperature glaze coatings for protection of refractory brickwork. Mr. Newcomb introduced a novel feature by illustrating his talk with actual demonstration of his subject through the use of a small electric furnace.

Two additional Committees, which had not been formed at the time of the first meeting of the Section, were announced. The formation of the two Committees—Membership Committee and By-Laws and Rules Committee—completes the organization of the New York Metropolitan Section. Membership of these two groups are: *Membership Committee*—Chairman, Don P. Falconer, F. E. Schundler & Company, Inc.; R. H. Sherwood, United Feldspar & Mineral Corp.; C. G. Fels, Seaboard Refractories; and C. L. Norton, Jr., Babcock & Wilcox Co. *By-Laws and Rules Committee*—Chairman, J. C. Crawford, Johns-Manville Corp.; Emerson W. Emrich, R. T. Vanderbilt Labs; M. H. Pickard, Pacific Coast Borax Co.; and S. D. Swan, Dentists' Supply Company.

An informal dinner was held in the meeting room preceding the meeting.

EX-SERVICEMEN REJOIN CHAS. TAYLOR SONS

The Chas. Taylor Sons Company has announced the return of W. C. Pittman and Felix Fraulini to their prewar jobs with the company. Both men have been serving with the U. S. Army and have obtained their honorable discharges.

Mr. Pittman will work as field engineer in Central and Southern Ohio, Central Indiana and West Virginia. Mr. Fraulini has been made general superintendent of the Special Refractories Plant at Taylor, Kentucky.

ORGANIZATION OF GEM GLASS COMPLETED

Organization of the Gem Glass Company has been completed with the election of officers and tentative plans set for starting production.

Chester L. Russell has been elected president of the firm, Frank Taylor, vice president, James E. Gard, secretary, J. E. Flatter, treasurer, and Henry Gradat, chairman of the board. Maurice Russell and George Jones complete the membership of the board.

According to the officials, the plant will probably start production around February 1, and samples are expected to be available early in March.

GENERAL ELECTRIC NAMES MANAGER GLASS MANUFACTURING

E. A. Howard, Manager of the Jackson Glass Works, has been named Manager of glass manufacturing for the

E. A. Howard J. T. Dent

Lamp Department of General Electric Company. J. T. Dent assumes Mr. Howard's former duties.

Mr. Howard, who will be in charge of all glass manufacturing activities of the Lamp Department, replaces K. G. Reider, who has been assigned new duties at the Lamp Department's Administration Division

A member of the company's staff since 1927, Mr. Howard has been with the Standardizing Division and the Engineering Division until, in 1937, he was transferred to the Glass Manufacturing Division. He had been manager of the Jackson Glass Works since 1941.

ORREFORS APPOINTS EASTERN REPRESENTATIVE

It has recently been announced by Orrefors Glassworks, of Cristalleries, Sweden, that Fisher Bruce & Company will represent the firm in the Eastern section of the United States.

The Fisher Bruce territory will include all the states east of Kansas City, while Axel Zacho will continue as West Coast representative.

Both the New York and Philadelphia showrooms of the firm will be redesigned to give adequate display to the Orrefors line.

DIAMOND ALKALI EXPANSION

Effective January 1, Diamond Alkali Sales Corporation took over the operation of the Baltimore and Boston branches of the Sunshine Soda Company. The Baltimore branch has emerged with Diamond's Philadelphia district office.

In Boston, a new Diamond Alkali sales office has been established. H. B. Clark is Sales Manager at the Boston branch.

At the same time, Diamond made known the appointment of R. B. Perry as District Sales Manager of the Memphis office to succeed E. A. Jones who has gone into business of his own. C. I. Brinkerhoff, formerly associated with the Memphis office, will take up new duties with the Benner Chemical Company, Chicago, distributors of Diamond Alkali products in the Middle West.

STRENGTH OF GLASS—
A REVIEW OF FOUR RECENT PAPERS . . .

(*Continued from page* 72)

however, that in both cases, the time coefficient K is the same.

The data of F. W. Preston[1] afford a means of checking the relation derived for the variation in strength with duration of loading. Preston found that the breaking strength of glass rods increased 3-fold as the time of loading decreased from 10^5 seconds to 10^{-2} seconds. These experimental results fall on a straight line when log (P-3) is plotted against log t. The equation of this line is found to be (see Fig. 5)

$$P_B - 3 = \frac{6.3}{{}_t 0.126} \qquad (5)$$

The value of 3 kg/mm² for the constant a in Murgatroyd's equation was obtained by trial to produce a straight line plot for Preston's data. It is interesting to compare the above expression with the one obtained by A. J. Holland and W. E. S. Turner[2] from their experimental work:

$$P = \frac{\text{Const}}{{}_t 0.078}$$

An enormous time span is covered by Preston's work,

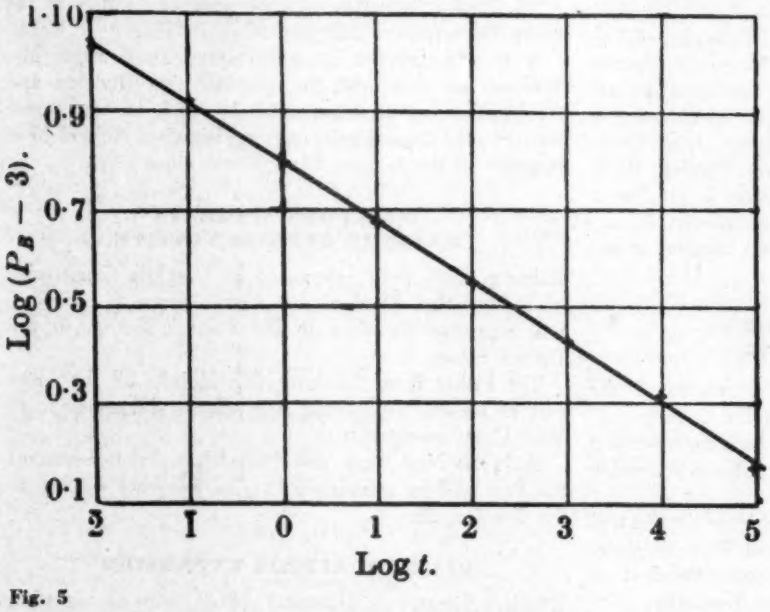


Fig. 5

and the ability of Murgatroyd's equation to satisfactorily cover this entire span is to be regarded as an accomplishment. It must be admitted, nonetheless, that this agreement does not necessarily prove the validity of the model. Dr. Haward, in the discussion of the paper, derives another expression based on different assumptions, and is also able to plot Preston's breaking stress vs. duration of loading data as a straight line.

Since Mr. Murgatroyd in reply then shows that Dr. Haward's equation is also derivable on the basis of the viscous pocket theory, no definite conclusion can be reached.

If it is assumed that the quasi-viscous material is susceptible to HF or water attack, the observed surface effects might be explained, and of course the theory explains the failure to discover the Griffith cracks. Some question is raised as to the compatibility of the assumed glass structure with X-Ray results. Possibly a more serious objection at the moment concerns the predictions regarding the variation of strength with temperature. The strength varies inversely with K. Since K should increase with increasing temperature, corresponding to a decrease in viscosity of the pocket material, the strength of glass might be expected to at first decline with increasing temperature. As soon as a temperature is reached at which the matrix itself can yield and release stress concentrations, the strength would begin to rise. However, this behavior is not found experimentally; if anything the strength of a soda-lime-silica glass continually increases with temperature, as mentioned by Professor W. E. S. Turner in the discussion of the paper, and by Dr. Jones in the fourth paper of this series.

An important test of the theory will be had when experimental data are available on the time constant of the delayed elastic effect to compare with that of the strength tests. The viscous pocket theory predicts that it will be identical in both cases. Possibly a continuation of the work reported in the following paper will provide an answer.

Determination of the Elastic and Viscous Properties of Glass at Temperatures Below the Annealing Range (Page 432)—

By G. O. Jones

In a previous paper[3] the mechanical strength of glass as a function of temperature was investigated. For the composition used the impact strength was found to be unaffected up to 30° to 40° C. below the transformation point, T_g = 534° C., while the strength under sustained loading increased somewhat. This same glass was now employed for a study of its elastic and viscous properties down to about 200°C. The results indicate that in this range the strain is made up of a purely viscous part, plus a completely reversible elastic part. The reversible elastic strain may in turn be resolved into an instantaneous and a delayed component. These phenomena are important in the general subject of the structure of glass, because the existence of a viscosity and a delayed elastic effect imply a mobility of atoms or group of atoms distinct from the instantaneous change of shape under stress. The substantial extension of the temperature range achieved in this paper contributes greatly toward clarifying these stress-strain relations.

The soda-lime-silica glass used had the following com-

(*Continued on page* 90)

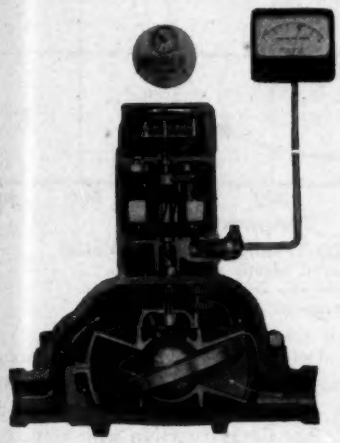
[1] F. W. Preston, J. Appl. Physics, 1942, 13, p. 623.
[2] A. J. Holland and W. E. S. Turner, J. Soc. Glass Tech., 1940 24, p. 46.
[3] G. O. Jones and W. E. S. Turner, J. Soc. Glass Tech. 1942, 26, p. 35.

NEW EQUIPMENT AND SUPPLIES

INDICATING FLOW METER

A new Veriflow Meter for measuring, indicating and totalizing various liquids used in industry has been announced by The Hays Corporation of Michigan City, Indiana.

The new meter is able to indicate the rate of flow at a point remote from where the meter is installed, in addi-



tion to the rate of flow indication and integrator which are integral with the meter itself.

To secure remote indication, the generator is mounted on top of the flow meter, the same shaft operating both the generator and the totalizing register. No external source of electricity is required because the indicating meter measures the output of the generator and is calibrated to indicate the corresponding rate of liquid flow through the meter. The scale of the indicator can be calibrated to read in any values of flow desired, such as gallons per minute.

AEROTEC PRESSURE SWITCHES

The Aerotec Company, White Plains, New York, has developed three new, eight ounce switches for either pressure or vacuum up to 200 pounds, in the control of liquids or gases that will not corrode brass.

Typical applications are to control compressors, pumps, carbonated beverage equipment. It is rated at 10 amp. on 110-volt ac. and is available in three designs.

Type M-500 has an externally adjustable range with a fixed differential, Type M-600 can be reset manually from the outside and Type M-700 has an adjustable differential. Contact arrangement in the first two can be specified as normally-closed, normally-open or double throw. The third design is available only with normally-open contacts. Pressure connection is by means of a ⅛ inch pipe nipple.

NEW RACK TYPE TRUCK

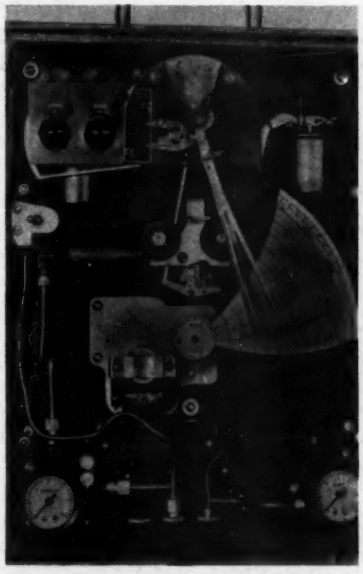
The Palmer-Shile Company, 7189 W. Jefferson Avenue, Detroit 17, Michigan, has announced a new rack type glass truck for handling flat glass in the warehouse. It is designed so that the handle will not contact glass even though the load extends beyond the end of the truck.

The framework is built of heavy angle iron, welded construction, faced with wood strips at all points of contact. Hinged type pull handle is of heavy tubing. The truck is equipped with four 6″ x 2″ roller-bearing casters —two of which are rigid and two swivel. Casters may be either all metal or metal with rubber tires. The truck is offered in dimensions to meet customers' specifications.

BROWN INTRODUCES NEW INDEXET

Brown Instrument Company of Philadelphia, Pa., has perfected a new device known as the "Adjustable Indexet". Two new mechanisms consisting of "span" and "zero" shift have been added.

The span or proportional adjustment permits a change between the span



through which the instrument control point is moved and the change in transmission pressure which moves the control point. Span dial is calibrated in terms of the distance in per cent of full scale that the control index will move along the chart per full scale changes in pressure. Span is the multiplying and dividing adjustment.

CATALOGUES RECEIVED

The Foxboro Company, Foxboro, Mass., has made available Catalogue 370 presenting the company's full line of recording and indicating instruments for measurement and control.

The sections of the catalogue deal with instruments for temperature applications, pressure humidity, flow, liquid level, density and other process variables. Control valves, planimeters, instrument accessories and supplies are included.

The catalogue is the first in which Foxboro has been able to show its line of Dynalog electronic instruments, the sale and use of which has, until recently, been limited to military applications.

Farris Engineering Company, 400 Commercial Avenue, Palisades Park, New Jersey, in its new catalogue, No. 45, describes a complete line of safety and relief valves including many new valve designs and improvements in old designs.

The catalogue features an index chart showing line drawings of all the basic Farris valve types. With the chart, a valve user can pick out the valve he needs without having to thumb through a whole catalogue. A supplemental bulletin supplies prices.

North American Philips Company, Inc., 100 East 42nd Street, New York 17, New York, has issued a booklet featuring X-ray equipment for fluoroscopy, radiography, diffraction and spectrometry.

Search Models 80 and 150 are described and specifications given. Radiograph illustrations show X-ray applications and a penetration (inches) chart is included. Descriptions and specifications are given on Searchray Model 150 CF (conveyor type) and Searchray Model 90 (mobile unit). X-ray Spectrometer and camera-type X-ray Diffraction units are also described. A convenient application chart shows which Searchray unit is best suited for a given task.

The B. F. Goodrich Chemical Company, Cleveland, Ohio, has issued a new 16-page booklet on its Geon polyvinyl materials.

Tables outline suggested applications and full details of properties are given. The four Geon resins, two polymers and two copolymers of vinyl chloride are described; many variations are discussed and properties listed. Methods for processing are outlined.

Discussion of Geon plastics, together with tables on electrical and chemical properties, methods of compounding and effects of various compounding practices, is one of the outstanding sections of the booklet.

(*Continued from page* 88)

position: SiO_2 72.29; R_2O_3 1.66; C_aO 8.77; M_gO 2.99; Na_2O 12.96; K_2O 0.87; SO_3 0.23. The transformation and softening points were determined from the thermal expansion curve to be 534° C. and 582° C. respectively. From sheet of average thickness 2.7mm, sample bars were diamond cut to a width of 5mm, their edges ground and polished, and the lower edges then slightly fire polished. Annealing was done by heating to 572° C. and cooling at ½° per minute.

The measurements were made by disposing the bar in the furnace as a centrally loaded horizontal beam and measuring the deflection as a function of time. The motion of the beam was communicated to the mirror of an optical level system by means of vertical fused silica rods extending from the sample to beyond the top of the furnace. This optical lever system produced a 266X magnification of the deflection of the bar. Scale deflections amounted to 5-6 cm. A new specimen was used for each run, and no attempt was made to stabilize the samples by extended heating. Temperatures were held to 1° C. A modified form of the apparatus is also suggested for measurements below 200° C.

The curve of a typical set of measurements is given in Fig. 6. The load was applied at A, resulting in the instantaneous strain AB, followed by the elastico-viscous strain BC. The load was chosen to give a stress of 10 kg/mm² at the mid-point of the lower surface, a value which was about the maximum that could be safely applied for long periods. At C the load was removed, and there was an instantaneous elastic recovery CD followed by a slow delayed elastic recovery DE.

It was not in general possible to continue an experiment to a point where the delayed elastic effect had completely decayed, and only pure viscous flow remained. Hence the curves were treated analytically to separate the elastic and the viscous components. This was done on the basis of two reasonable assumptions: 1. The total amount of delayed elastic effect which could appear a removing a load was equal to that part of the delaye elastic strain which had actually appeared during th time under load. 2. The decay function with respect t time was the same for loading and recovery, in th latter case reduced by a constant factor.

We can then write for the total strain-time relationshi

$$\text{Strain} = a + b \cdot t + c \cdot f(t) \quad (7$$

$$\text{Recovery} = a + nc\, f(t) \quad (8$$

where a is the instantaneous elastic strain, b · t is th pure viscous flow, c is the total delayed elastic strai n · c is the total elastic strain which actually occurre under a given load and f(t) is the decay function o the delayed elastic strain.

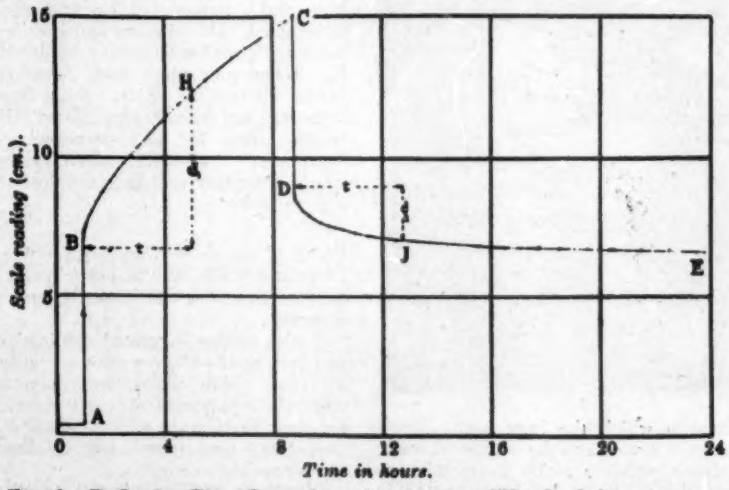


Fig. 6. Deflection-Time Curve for a Specimen at 473°, loaded so as to produce a stress in the lower surface of 10 kg./mm.². (Size of specimen 5 x 0·539 x 0·247₂ cm.) (Magnification of deflection by optical lever = 266.) AB and CD are the instantaneous deflections caused respectively by the application and removal of the load. d_1 and d_2 are the values of the non-instantaneous deflection and recovery respectively, after time t.

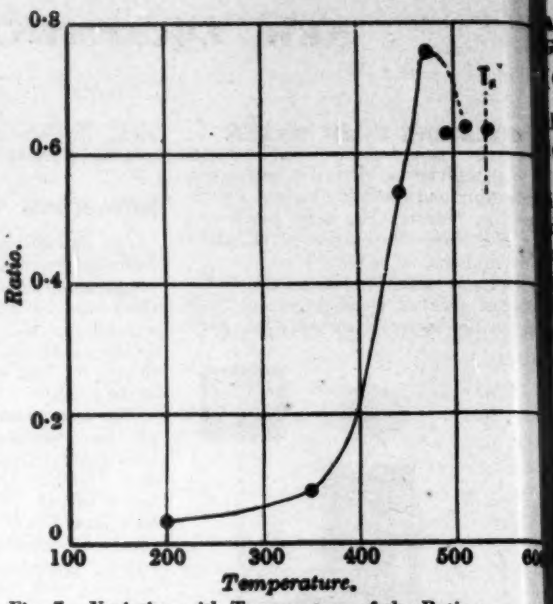


Fig. 7. Variation with Temperature of the Ratio: Delayed elastic deflection / Instantaneous elastic deflection

The non-instantaneous deflections d and d_2 occurring in time t after loadin or unloading respectively, are the given by

$$d_1 = b \cdot t + c \cdot f(t) \quad (9)$$

$$d_2 = n \cdot c \cdot f(t) \quad (10)$$

The fraction n of the total elastic strai which has developed up to the poin where the load is removed at C can b derived from the curve with the help o this latter pair of equations. For smal values of t the delayed elastic strain i larger than the viscous strain, hence

$$1/n = \lim_{t \to o} \frac{d_1}{d_2}$$

This limit was found graphically by plotting the ratio of the experimentally determined deflections d_1 and d_2 and extrapolating to time t = 0.

The viscous part of the flow can then be determined by plotting $(d_1 - d_2/n)$

(*Continued on page* 92)

A RUSSIAN HEAT INTERCEPTING GLASS . . .

(Continued from page 77)

than did IK-6, and in the visible region IK-6 passed at least twice as much as the silicate glass.

The transmission of the visible light was impaired by impurities. Titanium dioxide was found to be the most dangerous contamination; very small amounts of it caused a bad darkening of the glass. Probably the oxygen liberated by the high temperature dissociation of titanium dioxide oxidized ferrous oxide to ferric oxide and gave rise to discoloration in this manner; but the actual chemical reaction has not been investigated.

ELDRED ELECTED TO H-E BOARD OF DIRECTORS

Hartford-Empire Company has announced the election of five new directors to its Board of Directors who will fill vacancies which resulted following the end of the company's receivership.

Roger M. Eldred, one of the new Directors, has been Vice President and General Manager of the Hartford Empire Co. since 1936. The remaining four Directors are James H. Brewster, Jr., John B. Byrne, L. F. Robinson, Jr. and Thomas W. Russell.

Mr. Brewster is Vice President of the Aetna Life Insurance Co.; Mr. Byrne is President of the Hartford-Connecticut Trust Co.; Mr. Robinson is Senior Partner of the legal firm of Robinson & Cole; and Mr. Russell is an executive of Allen, Russell and Allen, insurance.

STEUBEN GLASS OFFICERS ELECTED

At a special meeting of the Board of Directors of Steuben Glass, Inc., Arthur A. Houghton, Jr., was elected President to succeed Robert J. Leavy, resigned. Mr. Houghton had previously been President but resigned to enter military service at which time Mr. Leavy was elected President to serve in his absence.

Charles D. LaFollette resigned as Vice President of Steuben Glass and Mr. Leavy was elected to take his place. Mr. LaFollette will continue to serve as a Director of the company.

John M. Gates was also elected a Vice President at the meeting. Mr. Gates has also been in the Service for a number of years.

PENN SALT NAMES DIRECTOR WHITEMARSH LABS

According to a recent announcement emanating from Pennsylvania Salt Manufacturing Company, Dr. W. A. LaLande, Jr., has been named Director of the Whitemarsh Research Laboratories.

Dr. LaLande has been associated with Pennsylvania Salt since 1944 when he joined the company in the capacity of Director of the Research Division. His new position will put him in charge of all activities at the new Whitemarsh Research Laboratories except those of the Patent Division. These activities include laboratory research, pilot plan operations, product evaluation studies and technical sales service work.

●Made from a special type of stainless developed exclusively for the glass industry, Jessop Cast-to-Shape molds and plungers will withstand high temperatures over a longer period of time. By using Jessop Cast-to-Shape molds and plungers, fire polishing is eliminated and yet a higher polished glass is produced.

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Jessop Cast-to-Shape steels are available in analyses to meet every requirement in the glass industry. Write for complete information, giving details of your requirements. Literature on request.

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STRENGTH OF GLASS— A REVIEW OF FOUR RECENT PAPERS . . .

(*Continued from page* 90)

against time. The slope of the resulting straight line is the constant b from which the viscosity n was derived.

The experimental data obviously permit the calculation of Young's modulus for the instantaneous elastic deflection.

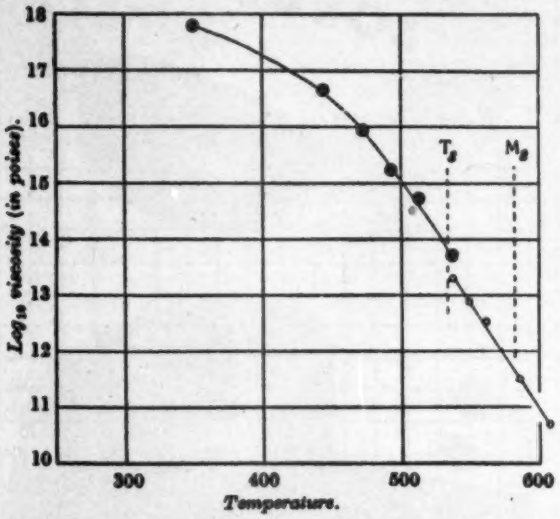

Fig. 8. Variation of Viscosity with Temperature, in and below the annealing range. ● By deflection of a glass strip. o By extension of a fibre.

Experiments were run at centigrade temperatures 537°, 513°, 493°, 473°, 444°, 350°, and 200°. At higher temperatures, aside from the fact that the strains become very large, it is difficult to separate the delayed elastic and viscous effects, since the former take place so rapidly, whereas at lower temperatures not only does the smallness of the deflections impair accuracy, but the delayed elastic effects are large in comparison with the viscous flow, and the latter tends to be obscured. The delayed elastic effect and Young's modulus were obtained for each of the above temperatures, the viscosity for all but the 200° run. The viscosity curve was then continued to 608° by using fibres. The results are presented in graphical form, Figs. 7, 8, and 9.

In Fig. 7 the total possible delayed elastic strain is plotted as a fraction c/a of the instantaneous elastic strain against temperatures. The estimated accuracy at 350° C. is ± 5 per cent, increasing to ± 20 per cent at either end of the curve. Whether or not the maximum is real, it is to be noted that the delayed elastic strain is very appreciable at the softening point T_g, amounting to 60 per cent of the instantaneous strain. At the other extreme, room temperature, extrapolation would indicate a value of 1 per cent.

The form of the decay function was examined at 350° C. For small values of t it was nearly linear, indicating a parabolic function; later, however, the decay becomes more rapid. At this temperature the delayed elastic effect was apparently complete in the time of the experiment, about 50 hours.

Parenthetically, it is interesting to note the fact that the increase in the strength of glass with temperature under sustained loading, found earlier by the author, taken together with the increase in delayed elastic effect recorded here, is a strong argument against the constant strain theory of glass failure. If glass were to break at a definite strain, it should be weaker under sustained loads at high temperatures, due to the additional strain arising from the increased delayed elastic effect.

The results on viscosities are given in Fig. 8, the measurements on the sample bars being supplemented by determinations with fibres at the high temperatures where the rate of bending of the bars becomes too large. The jog between the two curves may be due to the suspected difference between the structure of glass fibres and more massive pieces, since the accuracy is believed to be within 0.1 of log viscosity. A decreased viscosity of fibers was indicated by Mr. Murgatroyd in the first paper above. The value of $10^{17.8}$ poises at 350° C. is higher than any measured value previously reported. However, it is lower than would be expected by extrapolating linearly from higher temperatures, because the curve becomes definitely concave toward the origin. Such a behavior is, according to H. R. Lillie, indicative of the failure of the glass to reach a state of equilibrium corresponding to its temperature.

The variation with temperature of Young's modulus for the instantaneous elastic strain is shown in Fig. 9. At 300° C., it begins to drop appreciably. At the softening point, it has fallen to about 81 per cent of its room temperature value. It may be worthy of note that here again is a case of a decrease in E with increase in strength, at least under the sustained loading.

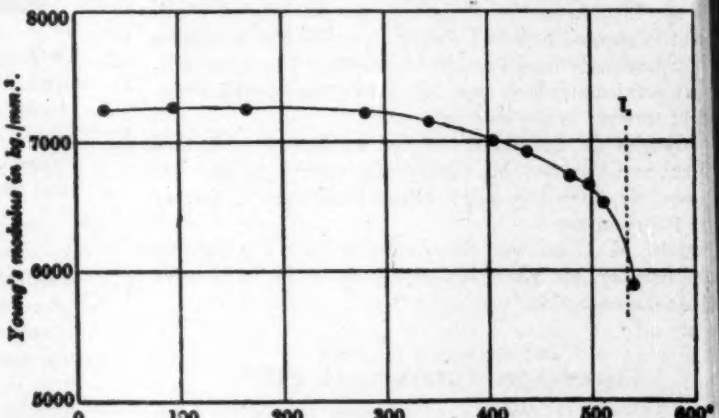

Fig. 9. Variation with Temperature of the Modulus of Instantaneous Elasticity (Young's modulus).

To summarize, this work has shown that equations 7 and 8, already established by N. W. Taylor and co-workers down to 50° below the softening point, is valid to at least 200° below the softening point, and hence presumably down to room temperature. The delayed elastic strain, expressed as a fraction of the instantaneous strain, decreases rapidly with falling temperature from

(*Continued on page* 94)

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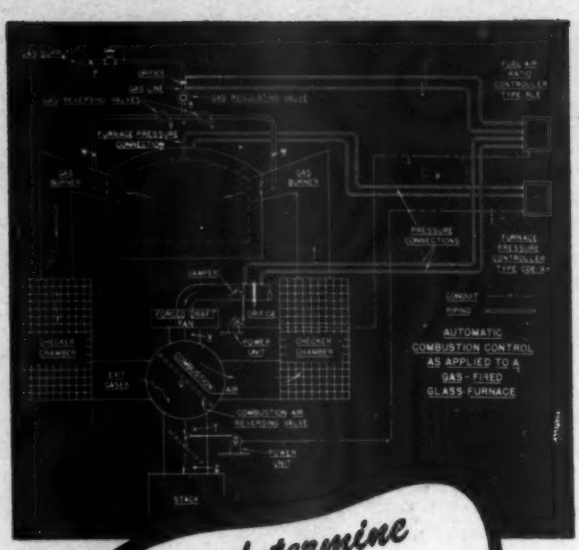

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EXPANSION BY ARMSTRONG

To facilitate handling the expanding business of the Glass and Closure Division of the Armstrong Cork Company in the West and South, the division has established four new District Offices at Dallas, Houston, Kansas City and New Orleans. The offices in these cities were formerly part of the St. Louis District Office.

Managers of the four new District Offices are Ralph E. Turner in Dallas, Ernest W. Foell in Houston, Austin M. Brown in Kansas City and Douglas J. Bell in New Orleans.

CZECH GLASS INSTITUTE ASKS FOR TECHNICAL BOOKS

A plea has been made by Dr. Vaclav Ctyroky, Director of the Glass Research Institute in Czechoslovakia, for American publications, books, and periodicals dealing with glass to help bring the war-depleted Institute library up to date.

Any reader of the THE GLASS INDUSTRY who may wish to donate material of this type, should send it directly to Dr. Vaclav Ctyroky, Director, Glass Research Institute, Hradec Kralove, Czechoslovakia.

STRENGTH OF GLASS—A REVIEW OF FOUR RECENT PAPERS . . .

(*Continued from page* 92)

.75 at 473° C., to .03 at 200° C. while at the same time there is an increase in both Young's modulus and the viscosity, which was followed as far down as 350° C.

Concluding Remarks

The above four papers furnish much new evidence on the elastic and viscous properties of glass. These will have to be taken into account in the further development of theories of the strength of glass. There appears to be a correlation between the elastic moduli, the viscosity and possibly the delayed elastic effect on the one hand, and the strength on the other. The structure of glass fibres apparently is not that of massive glass, but rather shows an anisotropic character, of the nature of a chain structure. There is further substantiation of the presence of a random distribution of flaws, and a proposed new explanation of their behavior. According to the latter, the strength of glass as a function of duration of loading and the delayed elastic strain should be closely related. Finally the strain-time relationships in glass appear to be composed wholly of an elastic and a viscous component.

Strictly speaking, one qualification must be applied to all these statements. The "glass" on which conclusions are based is almost invariably soda-lime-silica. The many other kinds of glasses, from pure silica through the "optical" glasses, and the recent rare earth glasses, remain practically untouched. Further, the chemical identity of the surface of the sample with the body of the glass is often tacitly assumed, despite some valid arguments to the contrary. This reviewer is certain that most glass technologists will agree with the remarks made during the discussion of these papers at the British Society of Glass Technology to the effect that a presentation of the influence of chemical factors on strength would be most welcome.

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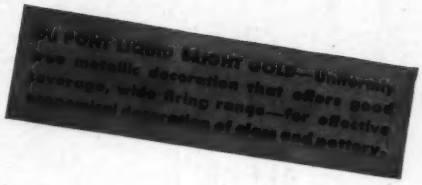
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(*Continued from page 76*)

the same decline of tensile strength with time as glass when the metal is tested in an atmosphere containing ammonia.

Ordinarily one does not think of the atmosphere as a corrosive medium and might question the justification and validity of these two comparisons; namely, glass in air with aluminum in sea water, and with brass in ammonia vapor. We shall add another example where, again, merely the atmosphere and this time the oxygen, rather than the moisture, exerts a "corroding" influence on an apparently very stable material—rubber. When tested in air the tensile strength of rubber decreases with time.

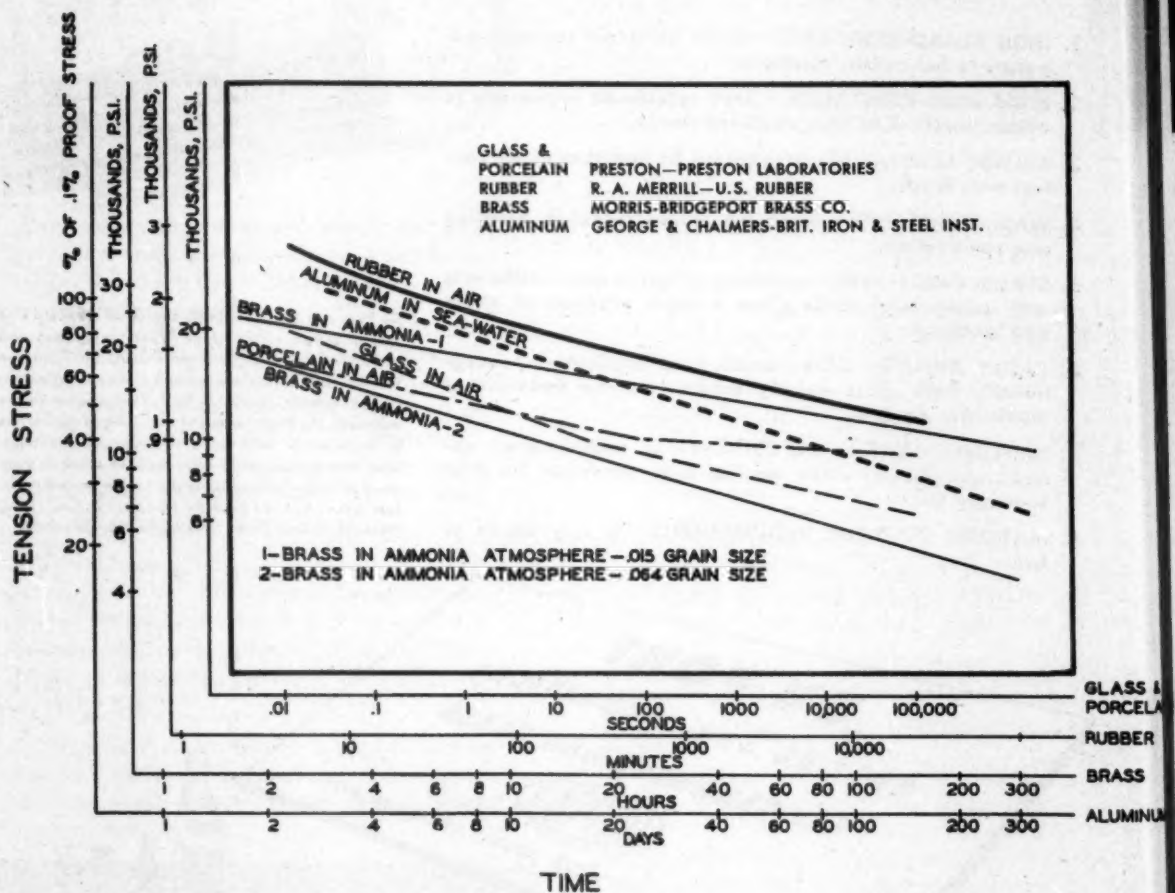
The corrosive influence of the atmosphere upon rubber becomes evident during the flexing test. A. M. Neal and A. J. Northam[45] flexed rubber in air, oxygen and nitrogen on a DuPont type flexing machine. Whereas there was no appreciable difference between the flexing in air and oxygen, they found that the uninhibited rubber flexed five times longer in nitrogen than in air before failure occurred. The presence of an antioxidant did not change its behavior in nitrogen but doubled its normal flex life in air. The authors conclude from their experiments that the fatigue failure of rubber on flexing is due to corrosion and not to a purely mechanical process.

The similarity of these "fatigue tests" is brought out in Fig. 9 where the log. of the tensile strength is plotted as a function of the log. of the time.* One glance at this diagram tells us that the "unique" failure of glass and porcelain under load of long duration is shared by metals and by rubber when these materials are tested under comparable conditions.

3. The tensile strength of glass as compared with the fatigue strength of metals. The difference in behavior of glasses and of metals when subjected to tension is based on their different reactions to the flaws. Both media contain flaws which act as stress raisers. In glasses a crack is formed as soon as the local tension at the apex of the most dangerous flaw exceeds the molecular strength. Such a crack having a very small radius of curvature at its apex continues to raise the stress and

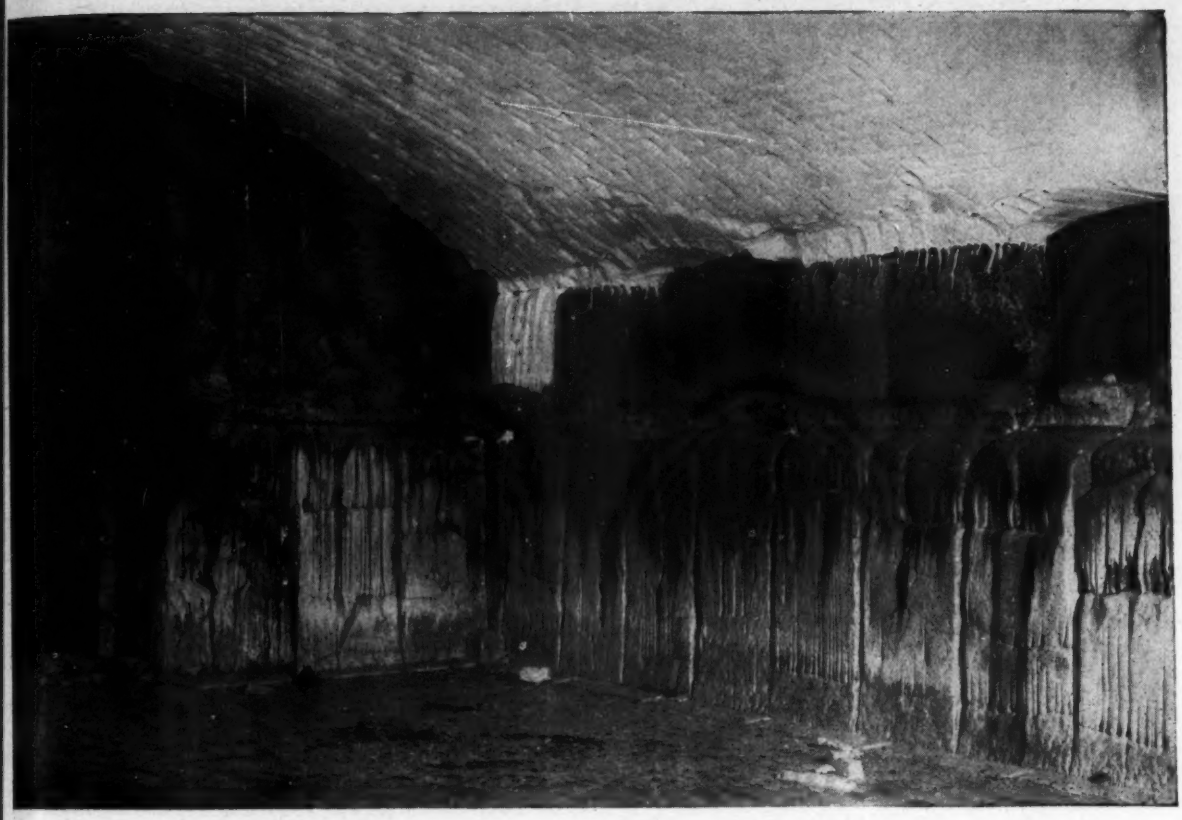
(*Continued on page 98*)

*This plot was obtained through the courtesy of J. O. Almen, Head of the Mechanical Engineering Dept., Research Laboratories, General Motors Corporation.


TENSION STRESS
% OF .1% PROOF STRESS
THOUSANDS, P.S.I.
THOUSANDS, P.S.I.
THOUSANDS, P.S.I.
GLASS & PORCELAIN — PRESTON—PRESTON LABORATORIES
RUBBER — R. A. MERRILL—U.S. RUBBER
BRASS — MORRIS-BRIDGEPORT BRASS CO.
ALUMINUM — GEORGE & CHALMERS-BRIT. IRON & STEEL INST.
RUBBER IN AIR
ALUMINUM IN SEA-WATER
BRASS IN AMMONIA-1
GLASS IN AIR
PORCELAIN IN AIR
BRASS IN AMMONIA-2
1—BRASS IN AMMONIA ATMOSPHERE—.015 GRAIN SIZE
2—BRASS IN AMMONIA ATMOSPHERE—.064 GRAIN SIZE
.01 .1 1 10 100 1000 10,000 100,000
SECONDS
1 10 100 1000 10,000
MINUTES
1 2 4 6 8 10 20 40 60 80 100 200 300
HOURS
1 2 4 6 8 10 20 40 60 80 100 200 300
DAYS
GLASS & PORCELA
RUBBER
BRASS
ALUMINU
TIME

CHEMICAL FATIGUE OF VARIOUS MATERIALS
(COURTESY J.O. ALMEN)

FIGURE 9



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A LITTLE over three years ago we published the story and operating data for a Corhart* flint-glass tank that had just finished a run of practically three years.

Today we are glad to report the results of that tank's successor—another "three-year" campaign just recently ended in which the melting and refining-end sidewalls, throat, doghouse and complete refining bottom of this unit were constructed with Corhart* Electrocast materials.

TOTAL DAYS	1,042
OPERATING DAYS	849
IDLE DAYS	193
MELTING AREA (SQ. FT.)	993
TOTAL TONS GLASS	141,029
CULLET RATIO	64.1%
TONS GLASS PER OPERATING DAY	166.1
TONS GLASS PER TOTAL DAYS	135.3
SQ. FT. PER TON PER TOTAL DAYS	7.3
SQ. FT. PER TON PER OPERATING DAY	6.0
TONS PER SQ. FT. PER LIFE	142

As we have said many times in the past, good production records are the result of good operation plus good refractories. Corhart* is glad to have had the opportunity of playing a part in this excellent performance.

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QUALITY ECONOMY ENDURANCE

CORHART ELECTROCAST REFRACTORIES

(*Continued from page* 96)

thus propagates perpendicularly to the direction of tension. In the metals the same would happen if the excessive stress were not partly released by plastic flow. As soon as the tension around the apex of the flaw exceeds a certain critical value, the yield value, the metal begins to flow, releasing some of the dangerous stress. At the same time atoms rearrange themselves at the surface of the molecular crack and assume positions which increase the radius of curvature.

The ability of a metal to flow at room temperature and thus evade the detrimental effects of flaws is not shared by glasses. Considering the rigidity of glasses and the plasticity of metals under excessive stress, a fair comparison of their strength properties becomes impossible under the conventional conditions of tensile strength testing. To bring both materials on a basis which would be suitable for a comparison, one has to do either one of two things: a) eliminate the possibility of stress release in metals under tension, or b) test the glass under conditions where dangerous stresses can be released through viscous flow. The second condition can be fulfilled easily by raising the temperature of the glass specimen sufficiently high. At room temperature, however, the glass is completely rigid.

As we are chiefly interested in strength properties at room temperature, we should look for conditions under which dissipation of the stress around flaws cannot take place in metals. In metals the plastic deformation does not go on forever. Plastic flow leads to a modification of the structure which is stronger and harder (work hardening), but which also has lost its ability to flow. Under oscillating stresses, therefore, metals will break under much smaller stresses than the critical tensile stress for rupture, as determined by static tests. The failure of metals under the influence of oscillating stresses is called "Fatigue." E. Orowan[46] explained the fatigue of metals as follows: The ability of a material to flow raises the static value of its modulus of rupture; specimens break after successive stress cycles for stresses lower than the static value, because the material has lost its ability to flow as a result of hardening.

H. F. Moore[47] in the "Edgar Marburg Lecture" of 1939, held before the American Society for Testing Materials, explained the effect of flaws on the strength of metals in a popular way, by comparing them with germs invading a human body. He writes, "Repeated stresses, intensified at many minute locations in a structural or machine part, keep trying to crack the material just as the thousands of disease germs in our bodies keep working to break down our resistance. Under attack the body automatically calls its reserve resisting powers into action, and the metal 'stiffens up' through cold work. But, alas, the body's resisting powers are not inexhaustible and the stiffening up by cold work uses up the ductility of the metal in the immediate vicinity of the crack. Under normal conditions the body preserves the balance of health, keeping the bacteria in check and the material stops the incipient crack without exhausting ductility in its vicinity. Under increase of bacterial attack or decrease of bodily resistance, the bacteria may conquer; so under increase of magnitude or number of repeated stresses the material may succumb."

Considering this characteristic behavior of metals under stress, we have found a basis on which to compare the different factors affecting the strength of glass and metals, e.g., the influence of surface structure and area. Both the fatigue strength of metals and the static tensile strength of glasses are greatly affected by the nature of the surface.

C. Brodman[48] (1894) found that the tensile strength of glass rods could be increased by 50% if one etched the surfaces smooth with hydrofluoric acid. This startling result has been confirmed many times in the past and has led to practical applications.

A light bulb rendered light diffusing by etching its inner surface with fluorides has lost most of its original mechanical strength because the treatment creates sharp edges and grooves. According to a process developed by C. D. Spencer and L. Ott,[49] its strength can be restored by a second treatment with diluted hydrofluoric acid. This bath rounds the sharp cracks and renders the dangerous flaws ineffective by increasing their radii.

With metals the nature of the surface is of little consequence when their tensile strength is measured in a static test. However, exactly the same influence of the surface on the strength of metals has been found when the metal is tested under oscillating stresses.

The metal specimens to be used for fatigue tests have to be polished and care has to be taken that the final polishing marks are parallel to the direction of the applied stress. These precautions were found to increase the fatigue strength and specimens finished in this manner are called "par-bars."

It has long been appreciated that the vulnerability to fatigue of metals increases with the surface roughness, particularly if the roughness consists of sharp notches oriented at right angles to the principal stress. It can be shown that even the "par-bars" with their fine polish parallel to the stress still contain flaws distributed over the surface which are impairing the fatigue strength. Here it may be recalled that work on the influence of scratches upon the fatigue of metals was the starting point of A. A. Griffith's research on glass.

Just as the tensile strength of a glass rod with the smoothest surface can be increased by bringing the surface layer into a state of compression, so the fatigue endurance of a "par-bar" can be increased by prestressing its surface under compression. Despite numerous observations pointing in this direction, the paramount importance and the benefit derived from prestressing the surface of metals apparently had not been realized fully among mechanical engineers until J. O. Almen[50] presented a coherent picture of these phenomena in his paper on "Improving Fatigue Strength of Machine Parts." In the following chapter we shall discuss the influence of surface compression on the static strength of glass and the fatigue strength of metals.

The similarities between the fatigue strength of metals and the static tensile strength of glass are not restricted to the influence of the surface structure. We have seen that the static tensile strength of glasses, as well as that of brittle three dimensional plastics, increases if the temperature is raised. At one time this behavior had been considered abnormal and unique. The same is

(*Continued on page* 100)

Doubtless, you've wanted release from frequent and costly belt replacements due to drag caused by dry bearings. • Possibly, too, you've wished for a lehr with alloy metal parts that would resist deterioration under heat... and thus avoid costly replacement shutdowns and repairs. • Well, here is just such a lehr, designed basically to avoid the weak points inherent in conventional lehrs. And proved an outstanding success for months in several varied installations. • Anti-friction pillow blocks, outside the housing, solve the belt drag problem. • Alloy heat-resisting steel avoids the shutdown and repair problems. • The Firoll method, used with great success in TECO Lehrs for years, assures highly efficient firing. • Write for information. Take the first step toward elimination of your lehr operating problems.

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(*Continued from page 98*)

true, however, for the strength of metals under oscillating stresses. For metals with high melting points, such as steel, the thermal softening during a fatigue test is very small. In other cases, especially at elevated temperature, its influence cannot be neglected. E. Orowan[46] concluded that "thermal softening" should increase the safe range of fatigue endurance of metals. This conclusion is affirmed by work of F. C. Lea.[51] Also, H. F. Moore and T. M. Jasper[52] found for steels and ferrous alloys that the fatigue endurance is practically constant or even increases slightly if the temperature is raised to 500°C. This is particularly significant because the ultimate tensile strength decreases in the same temperature interval to about one-half of its initial value.

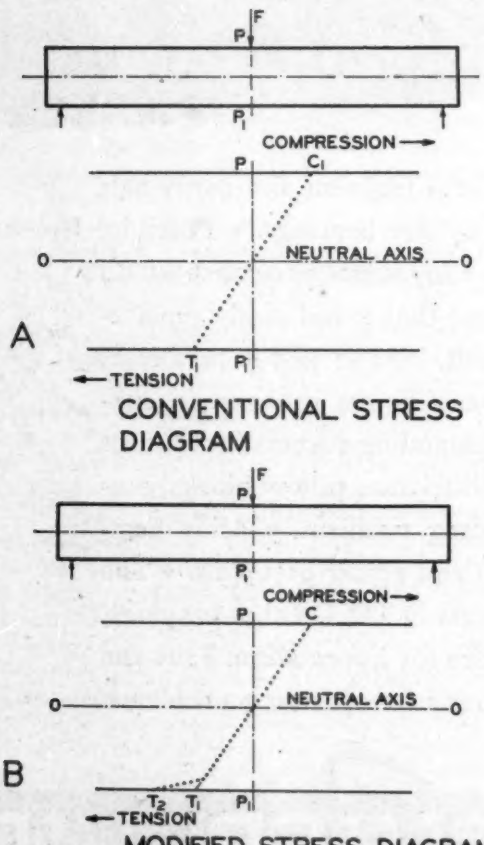
Taking into consideration the fact that the mechanism of rupture of brittle substances like glass is very much the same as that of the failure of ductile metals under oscillating stresses, one will not be surprised to learn that the appearance of the fracture is identical for both cases. A. Smekal,[12c] who made extensive studies on forms of fracture, remarked that in some cases the fracture of a glass rod broken under static load looks exactly like that of a metal which had failed under oscillated stresses.

4. The tensile strength of "toughened" glass as compared with the fatigue of metals prestressed under compression. The increase in strength which can be obtained by a controlled chilling operation is due to the glass surface being brought into a state of compression. This zone prevents the propagation of surface flaws and thus eliminates the first step of fracture which can be recognized by the mirror formation. It is not the constitutional change of the glass introduced through the heat treatment, but merely the stress distribution which is responsible for the improved strength properties. We will see that there are other methods to produce compression in the surface layer. For glasses the heat treatment is the one most frequently applied. For metals this method is less suitable because of their much higher thermal conductivity and because chilling a metal or an alloy might produce undesirable structural changes. The ductility of metals, however, offers another possibility to produce substantially the same result.

The history of toughening glass and of improving the strength of steel have much in common. Both processes have probably been discovered, forgotten and rediscovered many times. Some historians believe that the secret of the "unbreakable" toughened glass was known to the ancient Romans. There can be no doubt that the hardening of steel was certainly the secret of many famous ancient sword makers. Every village blacksmith knew and practiced this art in making wagon springs, axles and other heavily loaded parts. After these parts had been forged into shape they were severely hammered to improve their strength. It is surprising to learn that controlled treatment and scientific explanation of these phenomena started much earlier in the field of glass than in the otherwise more progressed field of metallurgy. The manufacture of prestressed lamp chimneys by De La Bastie[53] and the systematic work of O. Schott,[54] which led to the compound glass, belong to the past century. As late as 1929 O. Föppl[55] discovered the superiority of surface compressed machine parts. Research on the influence of surface compression on the strength of metals began with W. Zander,[56] who had found a strange paradox. Whereas, the roughening of a metal surface by means of fine grained abrasive was sufficient to decrease its strength substantially, no such weakening was found when deep surface notches were made by means of a chisel. The reason for this apparently paradoxical behavior is the zone of compression which surrounds the notches made by chisel blows. O. Föppl made systematic experiments with rods whose surfaces were pressed and thus proved the beneficial effect of a surface skin under compression on the fatigue endurance.

In order to account for the beneficial action of a prestressed surface layer, J. O. Almen[50] offered the same explanation which glass technologists used for explaining the increased tensile strength of toughened glass. He modified the conventional stress diagram to indicate the surface vulnerability. It might be practical for us to adopt this modification in dealing with the static strength of glass.

The conventional stress diagram of a loaded beam is illustrated in Fig. 10a. A beam supported at the ends



CONVENTIONAL AND MODIFIED STRESS DIAGRAM (AFTER ALMEN)

FIGURE 10

loaded in the central plane PP_1. The stress at any point in the beam is measured by the horizontal distance from the plane P in which the load is applied to the diagonal line T_1C_1. The distance PC_1 represents the compressive stress at the upper surface, the stress at the neutral axis OO is zero, and the tension at the lower surface is represented by the distance T_1P_1.

While this is a satisfactory stress diagram for metals under static loads, it does not agree with the behavior of glasses under the same conditions nor with that of metals under oscillating stresses. Almen, therefore, modified the diagram of Fig. 10a as shown in Fig. 10b. In the new diagram T_1T_2 represents an added increment of tension stress in the surface to bring in a reasonable representation of the surface vulnerability. The increment T_1T_2, which makes the facts agree with the theory, will depend on the number and size of the notches present at the surface. For a sharply notched surface the additional stress increment T_1T_2 is relatively great, but no matter how well polished the specimen may be, there still remains an additional surface stress as measured by fatigue tests.

T_1T_2 must also depend on the relative size of the surface, in other words, on the shape and dimensions of the specimens to be tested. This is particularly troublesome for those engaged in testing materials. H. F. Moore[47] discussed the possibility of testing the resistance to fracture of metals under repeated stress. He found that the most serious obstacles which interfere with this aim are the influences of size and stress history. Large fatigue specimens seem to develop lower endurance limits than smaller specimens of the same material. Some metals show this size effect to a marked degree, others scarcely at all.

Here we have again a perfect analogy between fatigue endurance of metals and static strength of glass. There is no better example than the tensile strength of glass fibers as a function of the diameter. (See VI. The abnormal strength of glass fibers.)

There must exist another possibility to bring out the strength of glass more advantageously, which should not be overlooked. A strength test based on high velocity impact does not give sufficient time to the metal to allow plastic flow and healing of flaws. Such a test applied to both glass and steel should produce results which come closer to the truth, at least as far as the actual cohesive forces are concerned.

TRENTON SECTION OF A.C.S. ORGANIZED

The Trustees of the American Ceramic Society have approved the organization of a Section in New Jersey to be known as the Trenton Section of the American Ceramic Society.

The Section organization becomes effective February 1. C. Forrest Tefft, President of the American Ceramic Society, will present the charter. The organization program will include a talk by J. W. Whittemore, Associate Dean of Engineering, Virginia Polytechnic Institute, who has recently returned from a tour of ceramic industries in Europe.

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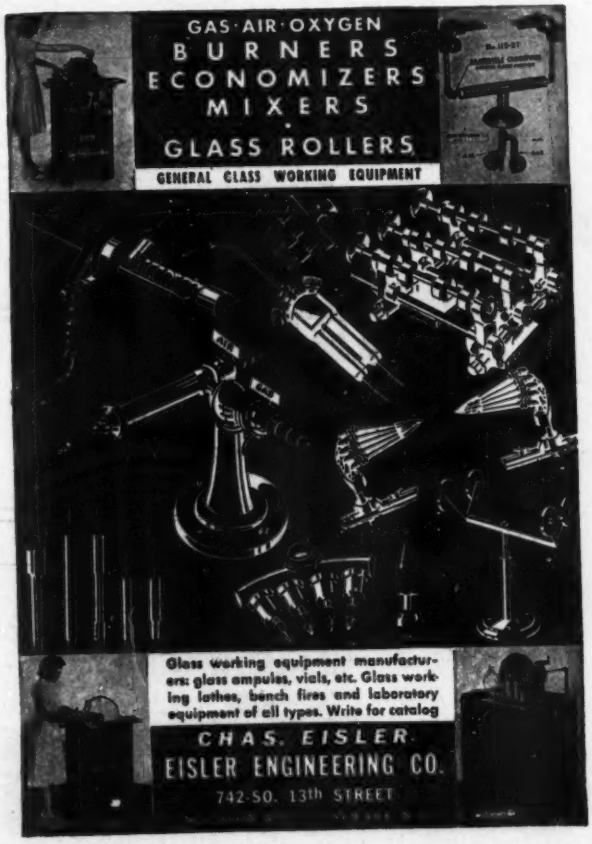
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INVENTIONS AND INVENTORS . . .
(*Continued from page 79*)

ity and chemical durability which consists of approximately 67-67.5% SiO_2, 15-16% B_2O_3, about 7.5% Al_2O_3, 1-3% Na_2O, 3-5% K_2O, and about 1% Li_2O and about 3% BaO, the electrical resistivity at 350° C. being over nine megohms per cm. cube and the setting point temperature of the glass being about 460° C. and its specific elongation between 25° C. and 460° C. being about 2.4×10^{-3} parts per unit length.

John C. Weber, Jr., of Weston, West Virginia, has assigned his patent No. 2,392,561 to the West Virginia Glass Specialty Company of the same town. The object of the invention is to provide a mold for use with hand gathering, in which a lid may be formed having a curved stem or handle terminating in a ball.

As shown in Fig. 5, each half of the hinged mold comprises a top 12 and body 13 and complemental parts 12a and 13a. In use, the gatherer marvers the gather which is then given to the blower who forms the stem 32 and ball 33 by hand tools. When this is placed in the mold and the mold is closed, the stem is bent over into the chamber 21. The lower part of the mold is provided with openings to permit quick cooling of the stem and ball. This appears to be a very satisfactory way of forming lids such as shown, for example, at 19 in the drawing.

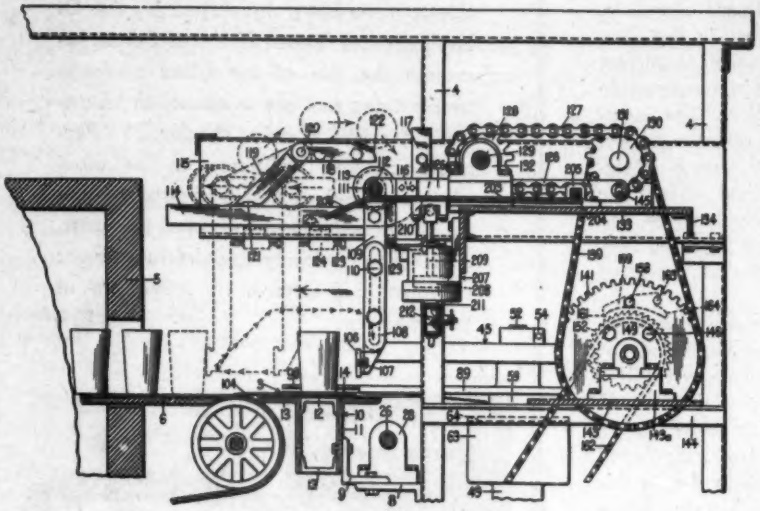

Fig. 4—Anchor Hocking Lehr Loader, Pat. No. 2,390,725.

Patent No. 2,392,770 discloses a method of bending laminated glass. It was assigned to Libbey-Owens-Ford Glass Co. by J. D. Ryan and G. R. Zolman.

It is well understood that laminated glass, as the term is generally used, refers to two sheets of glass with an interposed layer of

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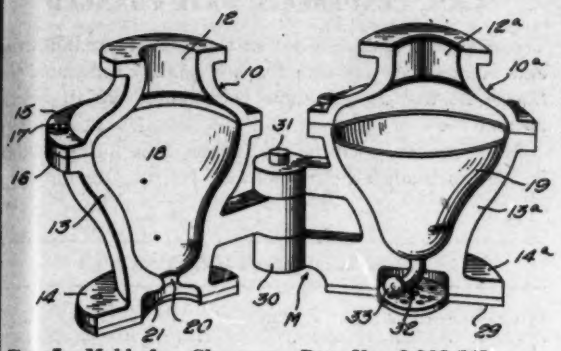

Fig. 5—Mold for Glassware, Pat. No. 2,392,561.

adherent thermoplastic. It has been customary to bend the glass sheets in pairs, the adjacent surfaces being prevented from sticking by a thin layer of "parting" material such as whiting, diatomaceous earth, and some other materials. The objection to all such materials was that after bending, the coating had to be carefully removed by a hand washing operation.

This patent proposes the use of a new parting material in the form of a water-soluble salt such as sodium sulphate or potassium sulphate. After the bending operation this material may be rinsed off without the necessity of any hand scrubbing operation. Such a parting material is not affected by the bending temperature, which is usually from 100 to 1250°F. and it does not injure the surface of the glass.

Fig. 6 shows a section through an apparatus for washing the glass and applying the parting material. The washing is done in a chamber 11, through which the glass 13 is fed by rollers 12. Brushes 14 clean the surfaces of the glass, aided by a suitable cleaning compound provided by spray nozzles 15. After washing, the glass is advanced by rollers 16 under one or more spray nozzles 19 which apply the parting material. One example of this novel parting material is a compound of 20 pounds of sodium sulphate dissolved in 100 pounds

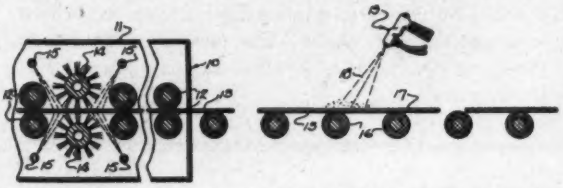

Fig. 6—Method of Bending Laminated Glass, Pat. No. 2,392,770.

of water. The addition of alcohol will hasten the drying operation. After drying, the sheets are superimposed in pairs and bent in the usual manner. The parting material is then removed by a simple spraying with water and the sheets are then ready to be made into "sandwiches" in any well known manner.

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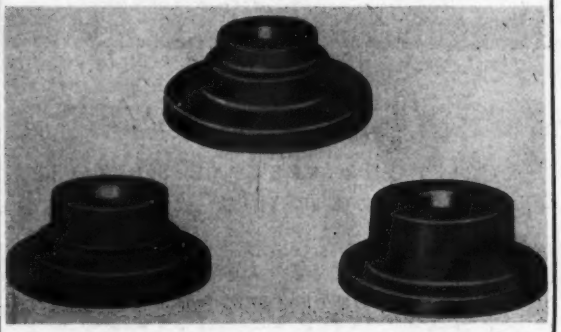

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